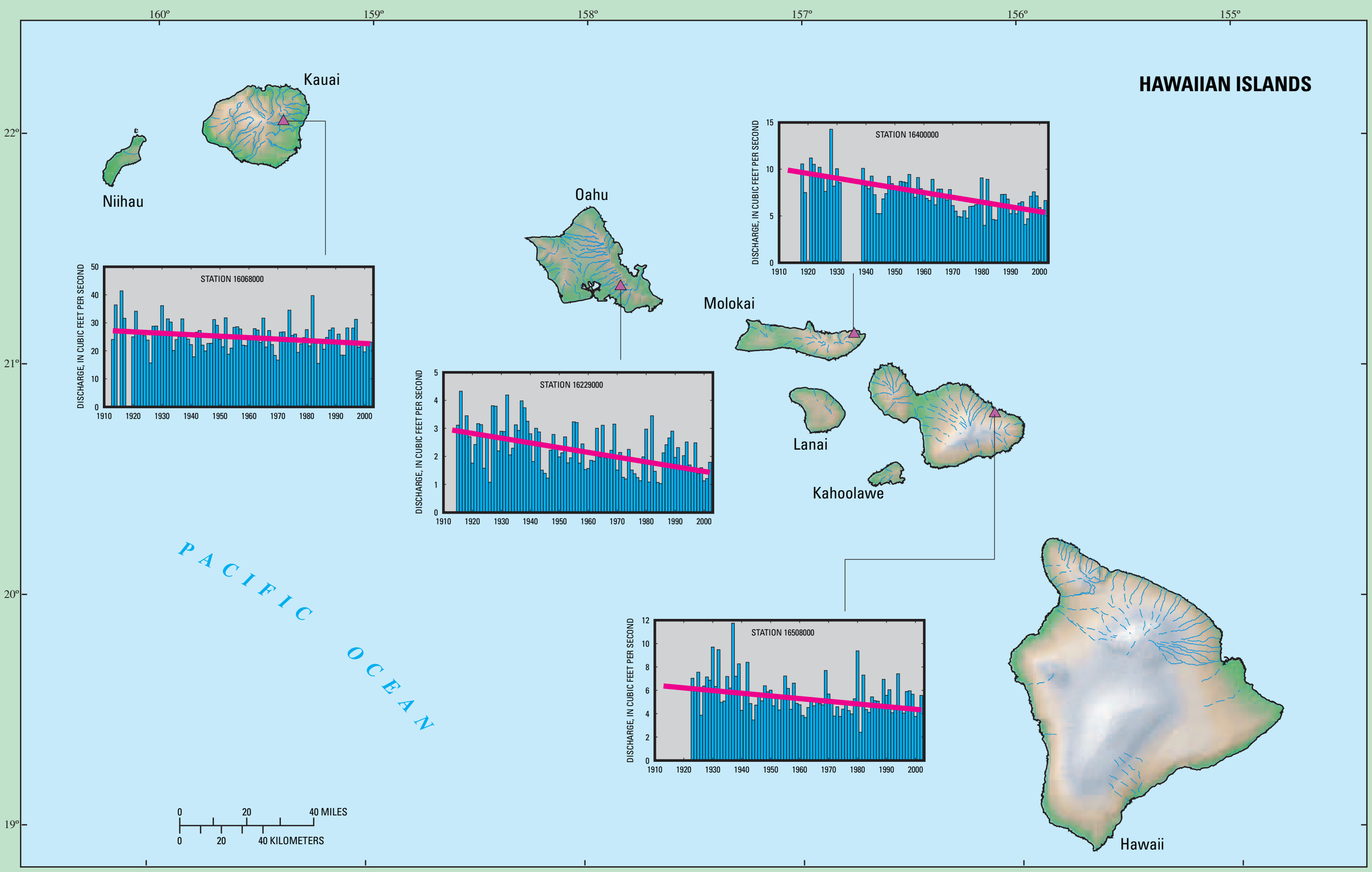
Prepared in cooperation with the

STATE OF HAWAII COMMISSION ON WATER RESOURCE MANAGEMENT, COUNTY OF MAUI DEPARTMENT OF WATER SUPPLY, and the U.S. GEOLOGICAL SURVEY BIOLOGICAL RESOURCES DISCIPLINE

Trends in Streamflow Characteristics at Long-Term Gaging Stations, Hawaii

U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Report 2004–5080



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By Delwyn S. Oki

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U.S. GEOLOGICAL SURVEY (BIOLOGY) GLOBAL CHANGE RESEARCH PROGRAM

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Conversion Factors

Multiply	**By**	**To obtain**
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced relative to mean sea level.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Trends in Streamflow Characteristics at Long-Term Gaging Stations, Hawaii

By Delwyn S. Oki

Abstract

The surface-water resources of Hawaii have significant cultural, aesthetic, ecologic, and economic importance. Proper management of the surface-water resources of the State requires an understanding of the long- and short-term variability in streamflow characteristics that may occur. The U.S. Geological Survey maintains a network of stream-gaging stations in Hawaii, including a number of stations with long-term streamflow records that can be used to evaluate long-term trends and short-term variability in flow characteristics.

The overall objective of this study is to obtain a better understanding of long-term trends and variations in streamflow on the islands of Hawaii, Maui, Molokai, Oahu, and Kauai, where long-term stream-gaging stations exist. This study includes (1) an analysis of long-term trends in flows (both total flow and estimated base flow) at 16 stream-gaging stations, (2) a description of patterns in trends within the State, and (3) discussion of possible regional factors (including rainfall) that are related to the observed trends and variations.

Results of this study indicate the following:

1. From 1913 to 2002 base flows generally decreased in streams for which data are available, and this trend is consistent with the long-term downward trend in annual rainfall over much of the State during that period.
2. Monthly mean base flows generally were above the long-term average from 1913 to the early 1940s and below average after the early 1940s to 2002, and this pattern is consistent with the detected downward trends in base flows from 1913 to 2002.
3. Long-term downward trends in base flows of streams may indicate a reduction in ground-water discharge to streams caused by a long-term decrease in ground-water storage and recharge.
4. From 1973 to 2002, trends in streamflow were spatially variable (up in some streams and down in others) and, with a few exceptions, generally were not statistically significant.
5. Short-term variability in streamflow is related to the seasons and to the EL Niño-Southern Oscillation phenomenon that may be partly modulated by the phase of the Pacific Decadal Oscillation.
6. At almost all of the long-term stream-gaging stations considered in this study, average total flow (and to a lesser extent average base flow) during the winter months of January to March tended to be low following El Niño periods and high following La Niña periods, and this tendency was accentuated during positive phases of the Pacific Decadal Oscillation.
7. The El Niño-Southern Oscillation phenomenon occurs at a relatively short time scale (a few to several years) and appears to be more strongly related to processes controlling rainfall and direct runoff than ground-water storage and base flow.

Long-term downward trends in base flows of streams may indicate a reduction in ground-water storage and recharge. Because ground water provides about 99 percent of Hawaii's domestic drinking water, a reduction in ground-water storage and recharge has serious implications for drinking-water availability. In addition, reduction in stream base flows may reduce habitat availability for native stream fauna and water availability for irrigation purposes.

Further study is needed to determine (1) whether the downward trends in base flows from 1913 to 2002 will continue or whether the observed pattern is part of a long-term cycle in which base flows may eventually return to levels measured during 1913 to the early 1940s, (2) the physical causes for the detected trends and variations in streamflow, and (3) whether regional climate indicators successfully can be used to predict streamflow trends and variations throughout the State. These needs for future study underscore the importance of maintaining a network of long-term-trend stream-gaging stations in Hawaii.

Introduction

In Hawaii, surface-water resources are developed for offstream uses including drinking water, agriculture, and industrial uses. The Hawaii State Water Code (Chapter 174C, Hawaii Revised Statutes) also recognizes beneficial instream uses including: (1) maintenance of fish and wildlife habitat, (2) outdoor recreational activities, (3) maintenance of ecosystems such as estuaries, wetlands, and stream vegetation, (4) aesthetic values such as waterfalls and scenic waterways, (5) maintenance of water quality, (6) conveyance of irrigation and domestic water supplies to downstream points of diversion, and (7) protection of traditional and customary Hawaiian rights.

Proper management of surface-water resources in Hawaii requires an understanding of long-term trends and variations in streamflow. Both short-term climatic variability and long-term climate changes affect streamflow and pose challenges to water users, water suppliers, and resource managers in the State. During periods of drought, low rainfall and reduced ground-water discharge to streams can affect the flow characteristics of streams and the instream and offstream uses of the water. Giambelluca and others (1991) identified 27 statewide droughts from 1895 through 1986, an average of about one drought every 3.3 years. Many of the droughts in Hawaii are related to El Niño events, which are associated with drier than normal winters in Hawaii (Giambelluca and others, 1991; Chu, 1995). At longer time scales, sustained climate change may lead to a long-term reduction in streamflow availability that has important water-management implications.

Since 1909, the U.S. Geological Survey has operated a total of about 500 stream-gaging stations on selected streams throughout Hawaii. Although many stations record only peak stages during storms, a significant number of stations continuously monitor stream stage and flow. A statewide analysis of trends in streamflow from these continuous-record stations has not been undertaken prior to this study.

Fontaine (1996) identified 20 stream-gaging stations in the State that would be useful, with continued data collection, to meet future goals associated with long-term trends (fig. 1, table 1). Selection of stations was based on two criteria: (1) drainage basins upstream of the stations should be free of artificial changes, and (2) stations need to be located in a variety of settings with different physical and climatological characteristics. Not all of the 20 stations identified by Fontaine (1996) are currently (2004) useful for identifying long-term trends. For example, the record at stream-gaging station 16501200 (Oheo Gulch at dam near Kipahulu) extends back only to 1988. Two stations on the island of Hawaii (16700000, Waiakea Stream near Mountain View, and 16764000, Hilea Gulch tributary near Honuapo) and one station on the island of Molokai (16414000, Kaunakakai Gulch near Kaunakakai) have been discontinued since they were first identified as candidates for long-term-trend stations. In addition, flow at station 16414000 on Molokai was occasionally augmented by an unknown amount of water from a water-development tunnel. The remaining 16 long-term-trend stations are active stream-gaging stations with flow data that can be analyzed for long-term trends.

Objectives

The overall objective of this study is to obtain a better understanding of long-term trends and variations in streamflow on the Hawaiian Islands of Hawaii, Maui, Molokai, Oahu, and Kauai. This study includes (1) an analysis of long-term trends in flows (both total flow and estimated base flow) at 16 of the long-term-trend stations identified by Fontaine (1996), (2) a description of patterns in trends within the State, and (3) discussion of possible regional factors (including rainfall) that are related to the observed trends and variations.

Purpose and Scope

This report addresses a need to provide a statewide analysis of trends in streamflow from continuous-record long-term stations. Daily mean discharge data collected by the U.S. Geological Survey at 16 long-term-trend stations are considered for analysis. Data collected during and prior to water year 2002 are used to determine monthly mean and annual mean flow values for both total streamflow and estimated base flow. Only water years with complete data are considered. (A water year covers the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends.) Trends in annual flow statistics are computed using a nonparametric trend test. Monthly mean flows are presented using a graphical technique designed to indicate periods of above and below average flows. Monthly mean flows also are correlated to a commonly used climate index.

Background

The Hawaiian Islands are geologically youngest in the southeast and oldest in the northwest. The eight main islands of the State of Hawaii and their approximate size, in square miles, from southeast to northwest are Hawaii, 4,021; Maui, 728; Kahoolawe, 45; Lanai, 141; Molokai, 259; Oahu, 603; Kauai, 553; and Niihau, 71. The island of Hawaii has the highest altitude in the State at 13,796 feet above sea level. The highest altitude on Maui is about 10,000 feet above sea level in its eastern part and about 5,800 feet above sea level in its western part; a broad lowland area separates the two parts. Molokai is mountainous in its eastern part, where it rises to an altitude of about 5,000 feet above sea level; however, most of the island is less than 1,000 feet above sea level. Oahu has a mountainous ridge along its eastern side and another mountainous area along the western side, where it rises to an altitude of about 4,000 feet above sea level; however, most of Oahu is less than 1,000 feet above sea level. The highest altitude on Kauai is about 5,200 feet above sea level in its central part; however, large areas of the island shoreward of the interior mountains are less than 1,000 feet above sea level. The main Hawaiian Islands can be divided into two primary physiographic zones, windward and leeward, which relate to the exposure of these areas to persistent northeasterly winds and orographic rainfall.

Atmospheric Circulation

The general atmospheric-circulation pattern in the Pacific has a strong effect on the climate in Hawaii (Sanderson, 1993; Giambelluca and Schroeder, 1998). The Hawaiian Islands lie within the influence of the Hadley cell, which consists of air that rises from the surface near the Equator, cools and moves poleward at high altitudes, sinks and warms by compression in a broad area near 30º north latitude, and returns to the Equator.

Table 1. Long-term-trend stream-gaging stations, Hawaii.
[--, not estimated]

Station	Station name	Years of record[a]	Mean annual rainfall, in inches[b]	N value used for base-flow separation[c]
Kauai				
16019000	Waialae Stream at altitude 3,820 feet near Waimea	61	160	5
16068000	East Branch of North Fork Wailua River near Lihue	87	130	4
16097500	Halaulani Stream at altitude 400 feet near Kilauea	44	110	4
16108000	Wainiha River near Hanalei	46	260	5
Oahu				
16200000	North Fork Kaukonahua Stream above Right Branch near Wahiawa	79	250	4
16211600	Makaha Stream near Makaha	43	70	4
16226000	North Halawa Stream near Honolulu	52	140	5
16229000	Kalihi Stream near Honolulu	88	120	5
16303003[d]	Punaluu Stream near Punaluu (combined flow of stations 16302000 and 16303000)	49	210	4
Molokai				
16400000	Halawa Stream near Halawa	77	80	5
16414000[e]	Kaunakakai Gulch near Kaunakakai	48	70	--
Maui				
16501200[f]	Oheo Gulch at dam near Kipahulu	9	--	--
16508000	Hanawi Stream near Nahiku	79	190	4
16587000	Honopou Stream near Huelo	91	170	5
16618000	Kahakuloa Stream near Honokohau	53	110	5
16620000	Honokohau Stream near Honokohau	84	240	4
Hawaii				
16700000[e]	Waiakea Stream near Mountain View	61	120	--
16717000	Honolii Stream near Papaikou	36	200	4
16720000	Kawainui Stream near Kamuela	38	170	4
16764000[e]	Hilea Gulch tributary near Honuapo	25	70	--

[a]Complete water years (through water year 2002).

[b]Average rainfall (over the drainage basin) estimated from Giambelluca and others, 1986.

[c]Base-flow separation using the method of Wahl and Wahl, 1995.

[d]Ditch records (station 16302000) for water year 1954 may be affected by unmeasured flow through a wasteway gate (Takasaki and others, 1969).

[e]Data not currently (2004) useful for analysis of long-term trends; station discontinued.

[f]Data not currently (2004) useful for analysis of long-term trends; record too short.

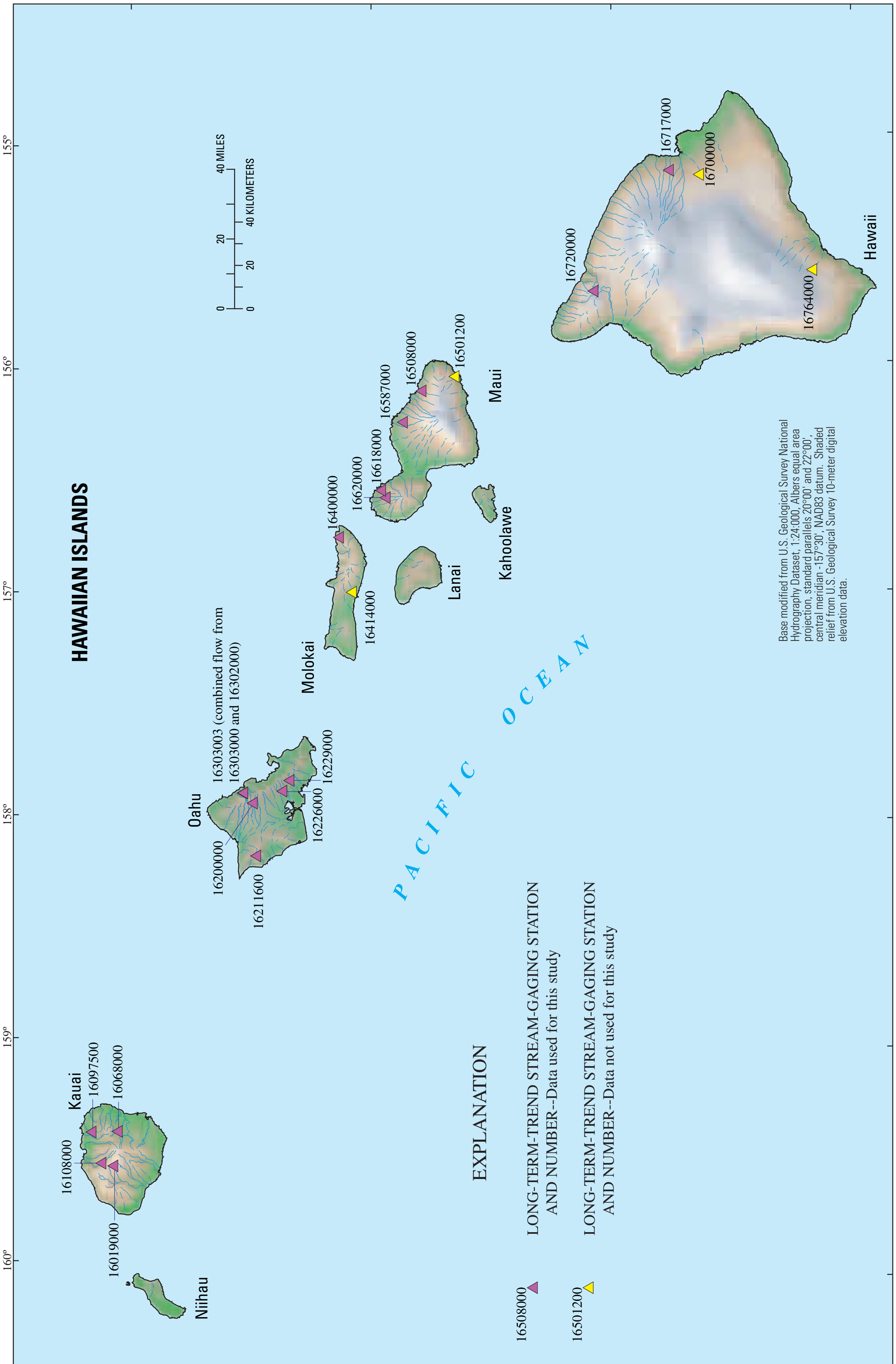

Figure 1. Long-term-trend stream-gaging stations (Fontaine, 1996), State of Hawaii.

Descending air from the Hadley cell near 30º north latitude creates an area of high pressure. The north Pacific anticyclone, located northeast of the Hawaiian Islands, is part of this high-pressure area and is a persistent surface feature. Surface air that blows toward the Equator from the north Pacific anticyclone is deflected by the rotation of the Earth and becomes persistent northeasterly winds, known locally in Hawaii as trade winds.

Descending air from the Hadley cell warms by compression and meets ascending air that has cooled from the surface. A layer in which warmer air overlies cooler air forms where the descending and ascending air meet. This temperature inversion, where air temperature increases rather than decreases with altitude, is known as the trade-wind inversion in Hawaii. The inversion altitude varies from day to day and is commonly between 5,000 and 10,000 feet (Giambelluca and Schroeder, 1998). Because the trade-wind inversion inhibits the rise of moist surface air, the level of clouds is capped and air above the inversion is relatively dry.

Climate

In general, mild temperatures, cool and persistent northeasterly winds, a rainy season from October through April, and a dry season from May through September characterize the climate of Hawaii (Blumenstock and Price, 1967; Sanderson, 1993). The location of the north Pacific anticyclone relative to the Hawaiian Islands is one of the primary climate controls.

The north Pacific anticyclone is farther north and stronger during the dry season relative to the wet season. During July (middle of dry season), the high-pressure area is near 38º north latitude, 150º west longitude, and the central pressure is about 1,025 millibars; in comparison, during January (middle of wet season), the high-pressure area is near 32º north latitude, 130º west longitude, and the central pressure is about 1,021 millibars (Schroeder, 1993). During the dry season, the stability of the north Pacific anticyclone produces persistent northeasterly winds that blow 80 to 95 percent of the time. During the rainy season, migratory low- and high-pressure systems and frontal systems often move past the Hawaiian Islands, resulting in less persistent trade winds that blow 50 to 80 percent of the time (Sanderson, 1993).

Rainfall

The topography of each island has a profound effect on rainfall. In general, the northeastern, or windward sides of the islands, are wettest. This pattern is controlled by the rise of moisture-laden northeasterly trade winds along the windward slopes of the islands (see for example Sanderson, 1993). When the moisture-laden air mass rises and cools, the moisture condenses and may precipitate on mountain slopes. Maximum rainfall occurs between altitudes of 2,000 and 6,000 feet above sea level, but amounts vary depending on the form, location, and topography of each island. Precipitation also may occur as fog drip, which is cloud vapor that is intercepted by vegetation and that subsequently drips to the ground. Fog drip also is greatest between altitudes of 2,000 and 6,000 feet. Above 6,000 feet, precipitation decreases and the highest altitudes are semiarid. High mountain areas are dry because the upslope flow of moist air is prevented from penetrating above altitudes of about 6,000 to 8,000 feet by the temperature inversion in the atmosphere. Areas that are leeward (southwest) of mountain barriers generally are drier than windward areas because air loses moisture during its ascent over an upwind barrier. This is known as the rain-shadow effect (Giambelluca and others, 1986).

Mean annual rainfall exceeds 235 in. on the northeastern part of the island of Hawaii, 275 in. on the northeastern parts of Maui and Oahu, 155 in. on the mountainous parts of eastern Molokai, and 435 in. near the central summit area of Kauai (Giambelluca and others, 1986) (fig. 2). Most of the southwestern coastal areas of all islands receive less than 40 in. of rain annually; the island of Hawaii has areas at high altitudes, above the temperature inversion, that receive less than 20 in. Mean annual rainfall changes significantly over short horizontal distances; in some places, this change can exceed 100 in. over a horizontal distance of 1 mile.

Migratory low-pressure systems and frontal systems can bring heavy rains to the islands. The dry coastal leeward areas can receive much of their rainfall during a year because of these systems. In Hawaii, 24-hour rainfall totals can exceed 10 in. over coastal areas and 20 in. over the mountainous interior areas during heavy storms (U.S. Weather Bureau, 1962; Giambelluca and others, 1984).

Surface Water

Most Hawaiian streams originate in the mountainous interiors of the islands and terminate at the coast. Streams are significant sculptors of the Hawaiian landscape because of the erosive power of the water they convey. In geologically young areas, such as much of the southern part of the island of Hawaii, well-defined stream channels have not developed because the permeability of the surface rocks generally is so high that rainfall infiltrates before flowing for significant distances on the surface. In geologically older areas that have received significant rainfall, streams and mass wasting have carved out large valleys (Oki, 2003).

Streamflow in Hawaii is highly variable both in space and time. Streams that are dry most of the year are common in the drier, leeward parts of the islands. Streams that flow continuously throughout the year are common in areas that receive significant rainfall and ground-water discharge. Seasonal streamflow variations exist over both windward and leeward areas, but they are commonly less pronounced in windward areas where base flow is significant and rainfall is persistent. During periods of little or no rainfall, the flow characteristics of a stream are primarily dependent on base flow (ground-water discharges). Periods of less than average rainfall may

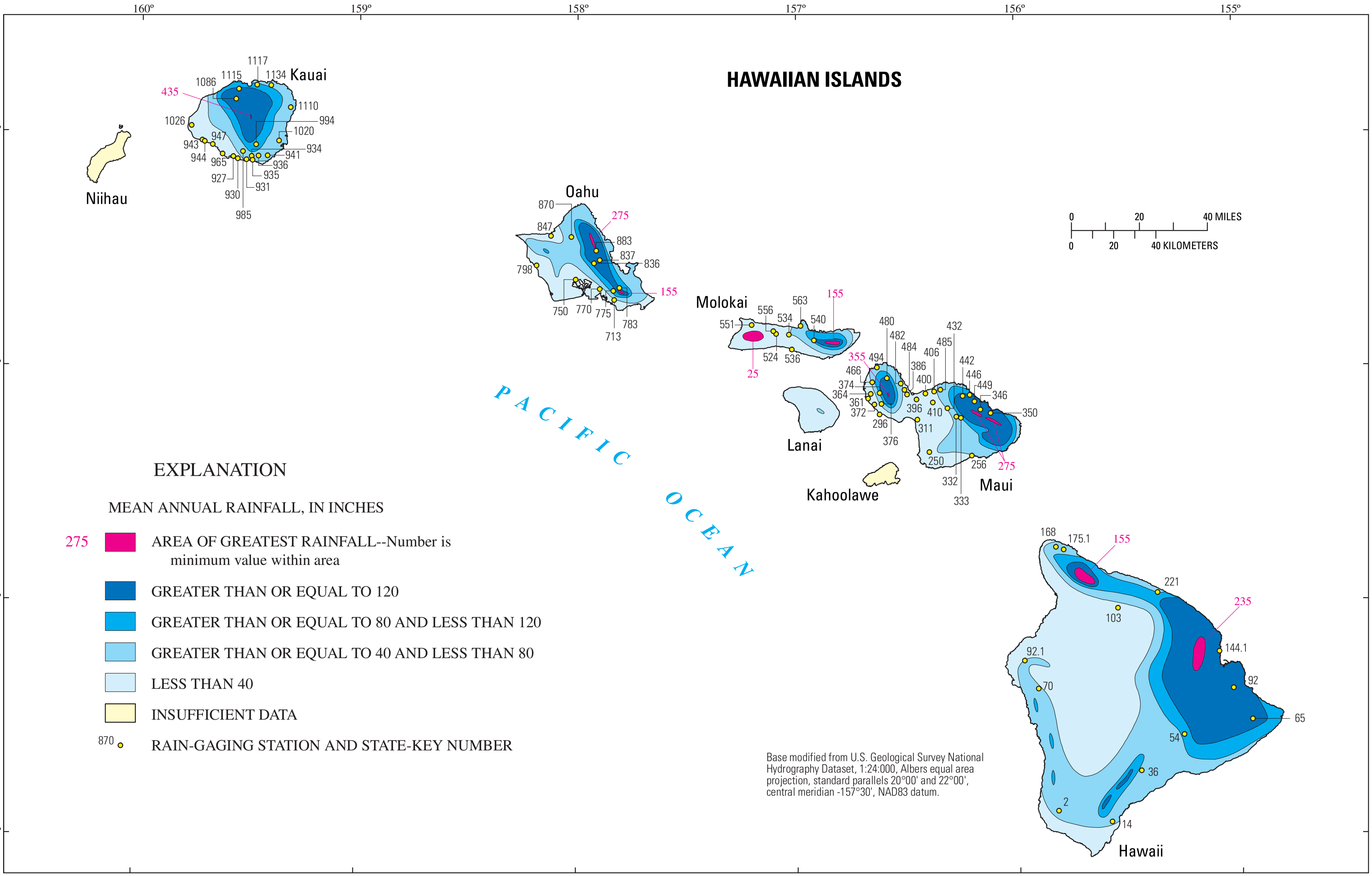

Figure 2. Mean annual rainfall and selected rain-gaging stations, State of Hawaii. Contours of mean annual rainfall (modified from Giambelluca and others, 1986) were based on many additional rain-gaging stations that are not shown.

be related to climatic cycles and result in periods of less than long-term average streamflow at a site. Periods of less than average streamflow also can be caused by upstream surface-water diversions or nearby ground-water withdrawals that reduce base flow.

The percentage of rainfall that directly runs off varies both among basins and within a basin. Among basins, the percentage of mean annual rainfall that runs off typically ranges between 10 and 40 percent, although higher and lower values exist in places. Within a basin, the percentage of rainfall that runs off varies temporally among individual storms and may range from less than 5 to greater than 50 percent (Oki, 2003). The percentage of rainfall that runs off is expected to be high where the rainfall amount and intensity are high, permeability of the soils is low, slopes are steep, the water table is at or near the land surface, or antecedent soil moisture is high.

The flow that is equaled or exceeded 90 percent of the time (Q_{90} flow) is commonly used to characterize low flows in a stream. In Hawaii, Q_{90} flows may range from near zero for ephemeral streams in areas that receive little rainfall, to tens of cubic feet per second in areas that receive significant rainfall or ground-water discharge. Q_{90} flows commonly are less than estimated long-term average values of base flow at a site. For perennial streams, estimated long-term average base flow is commonly exceeded less than 70 percent of the time (Oki, 2003).

El Niño-Southern Oscillation and the Pacific Decadal Oscillation

Regional climatic phenomena, including the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), may affect streamflow in Hawaii. Whereas the pattern of ocean-atmosphere variability associated with ENSO generally recurs on the time scale of a few to several years and mainly affects tropical regions, the pattern of ocean-atmosphere variability associated with the PDO generally recurs on the time scale of a few to several decades and mainly affects the north Pacific.

In Hawaii, drier than normal winter months commonly follow ENSO events (Chu, 1995). The ENSO phenomenon is characterized by variations in sea-surface temperature, atmospheric pressure, and circulation patterns in the tropical Pacific. Under average conditions, cool waters and high atmospheric pressure exist in the eastern tropical Pacific relative to the western tropical Pacific, and winds generally blow from east to west. El Niño and La Niña conditions represent variations from the average conditions. During El Niño conditions, waters warm and atmospheric pressure decreases in the eastern tropical Pacific and easterly winds slacken. The counterpart to El Niño is La Niña, during which waters in the eastern tropical Pacific are cooler than average.

Associated with El Niño conditions is the southern oscillation, which refers to the seesaw variations in atmospheric pressure, measured at the surface, between the eastern and western tropical Pacific. During El Niño conditions, atmospheric pressure in the eastern tropical Pacific decreases relative to atmospheric pressure in the western tropical Pacific. The Southern Oscillation Index (SOI) is a measure of the difference in atmospheric pressure between Tahiti and Darwin, Australia (see for example Trenberth, 1984). Large negative SOI values are associated with El Niño conditions, whereas large positive SOI values are associated with La Niña conditions (fig. 3).

Variations in sea-surface temperature in the north Pacific occur on both interannual and decadal time scales (see for example Yeh and Kirtman, 2003). One indicator of the decadal variations in sea-surface temperature in the north Pacific is the PDO (Mantua and others, 1997). The PDO refers to a recurring pattern of ocean-atmosphere climate variability centered over the mid-latitude north Pacific and may be related to variations in ocean and air temperatures, as well as streamflow near the northwestern coast of the United States (Mantua and others, 1997).

The PDO index, which is the leading principal component from an empirical orthogonal function analysis of sea-surface temperature anomalies in the north Pacific poleward of 20º N (Mantua, 2003), indicates that the PDO phase was mainly positive during 1925–1946 and 1977–1998 and mainly negative during 1947–1976 (Mantua and others, 1997) (fig. 3). During 1910–1924, the PDO phase was mainly negative, although a brief period of positive PDO phase occurred during 1913–1915. During 1998–2002, the PDO phase appears to be predominantly negative, although it is uncertain whether this negative phase will persist in the future. Positive PDO phases are characterized by cooler than average sea-surface temperatures in the central north Pacific and warmer than average sea-surface temperatures near the western coast of North America. Mantua and others (1997) indicated that the PDO index is negatively correlated with the SOI and winter precipitation over the Hawaiian Islands, although the effects of topography on rainfall in Hawaii were probably not considered.

Data

For this study, information related to streamflow, rainfall, and regional climate indices were used to evaluate trends and variations in streamflow characteristics. Daily mean discharge data collected by the U.S. Geological Survey from 16 long-term-trend stations (fig. 1) were used to determine monthly mean and annual mean flow values. Only water years with complete data were considered. Data for water year 1954 for station 16303003 were excluded from the analysis because records may have been affected by unmeasured flow from a wasteway gate (Takasaki and others, 1969).

Annual mean, Q_{10}, Q_{25}, Q_{50}, Q_{75}, and Q_{90} flows (total flow and base-flow component of total flow) were computed for each water year (figs. A1-A16). The annual Q_p flow is the daily mean flow that is equaled or exceeded p percent of the

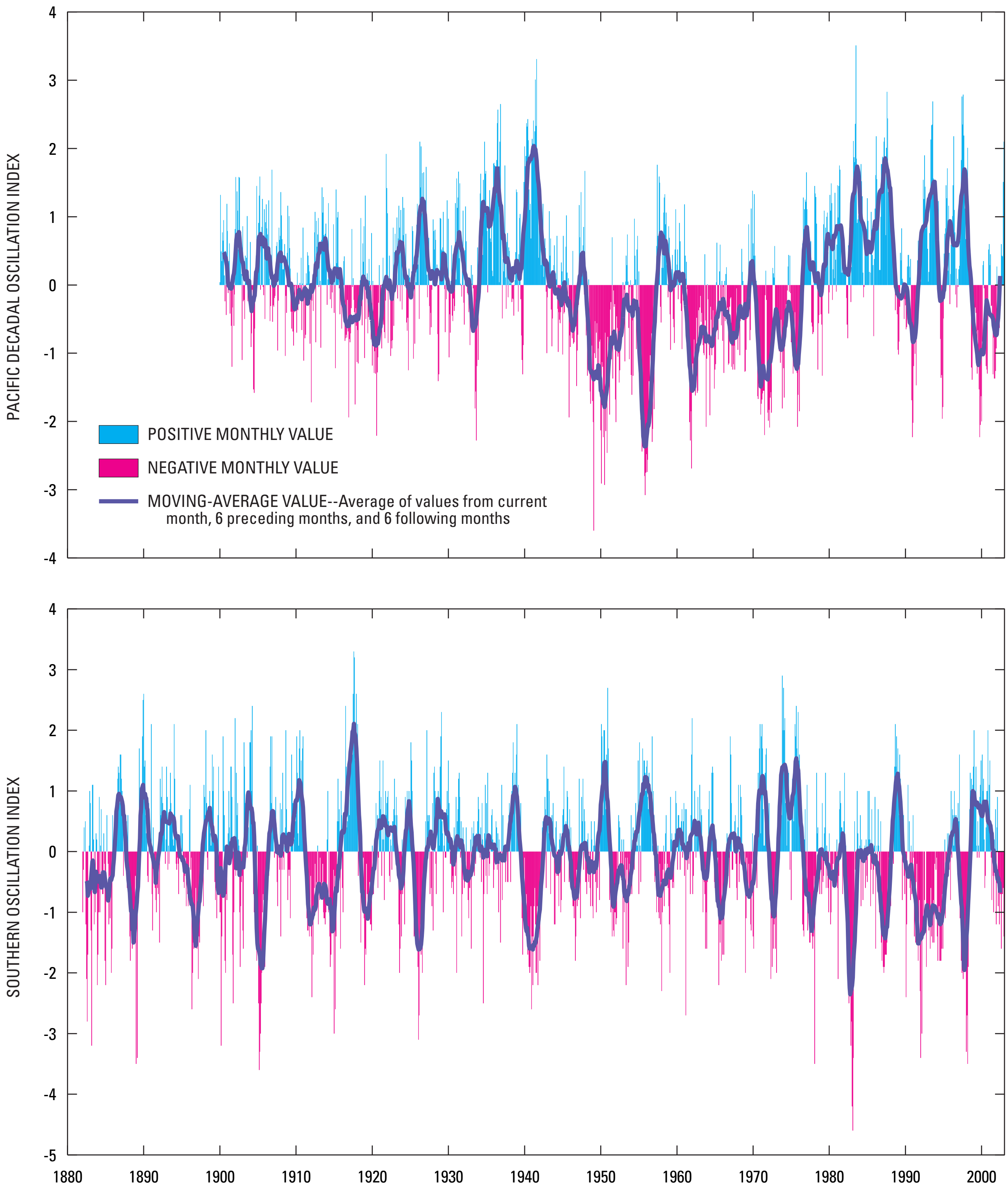

Figure 3. Pacific Decadal Oscillation (PDO) index and Southern Oscillation Index (SOI). Monthly PDO-index values from Mantua (2003); monthly SOI values from National Weather Service (2003) with missing values generated using Tahiti sea-level pressure data from Commonwealth of Australia (2003).

time during the year. The Q_{50}, or median flow, is the flow that is equaled or exceeded 50 percent of the time. Base flow was estimated from the total flow hydrograph using a computerized base-flow separation method (see section on "Methods"). In addition to the percentile flows, the annual minimum and maximum consecutive 1-, 7-, and 30-day mean flows (figs. A1–A16) and monthly mean flows also were computed.

Rainfall data were obtained from the Hawaii Commission on Water Resource Management (CWRM) and the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration. Rainfall data from CWRM were in the form of monthly rainfall totals through 1986, and these data were updated through 2001 using daily rainfall from NCDC (National Climatic Data Center, 2002). Stations with long-term data identified by Giambelluca and others (1986) were considered for analysis in this study. Annual rainfall totals for the stations used in this study (fig. 2) were computed for calendar years through 2001 (figs. B1–B5 in Appendix B).

Monthly values of the SOI were obtained from the National Weather Service, Climate Prediction Center (National Weather Service, 2003). Missing SOI values were computed using reconstructed Tahiti sea-level pressure data (Commonwealth of Australia, 2003) and available Darwin sea-level pressure data (National Weather Service, 2003). Monthly values of the PDO index, which are derived from the leading principal component of monthly sea-surface temperature anomalies in the North Pacific Ocean, were obtained from Mantua (2003) (fig. 3).

Methods

To meet the overall objective of this study, streamflow data from 16 of the 20 long-term-trend stations identified by Fontaine (1996) (table 1) were analyzed. Both total flow, which includes direct runoff and base flow, and the base-flow component of total flow at each of the 16 stream-gaging stations, as well as rainfall from selected rain-gaging stations (fig. 2), were statistically analyzed for long-term trends using the Mann-Kendall test (also referred to as the Kendall-tau test). Base flow was estimated using a computerized base-flow separation method. The effects of interannual and decadal climate variability on mean flows at the 16 stream-gaging stations also were analyzed by determining the relation among flow, the SOI, and the PDO index.

Estimation of Base Flow

The base-flow component of total flow (daily mean values) was estimated using a computerized base-flow separation method (Wahl and Wahl, 1995). This method previously has been used for streams on Molokai, Kauai, and Maui to estimate base flow (Oki, 1997; Izuka and Gingerich, 1998; Gingerich, 1999). The base-flow separation method requires estimates of two parameters: *f* (turning-point test factor) and *N* (number of days in window). The model divides the daily streamflow record into non-overlapping *N*-day periods and determines the minimum flow within each *N*-day window. If the minimum flow within a given *N*-day window is less than *f* times the adjacent minimums, then the central window is made a turning point on the base-flow hydrograph. The length of the *N*-day window for a stream is an indicator of the time over which direct runoff occurs following a storm.

For each of the 16 long-term-trend stations used for this study, values for *f* and *N* were estimated using the method described by Wahl and Wahl (1995). The *f* value used for all stations was 0.9. The *N* values used ranged from 4 to 5 days (table 1).

Cumulative Monthly Departures

Trends in time series sometimes are visualized readily using a graphical technique that involves plotting the cumulative rescaled departures as a function of time (Bales and Pope, 2001; Garbrecht and Fernandez, 1994). For this study, departures of monthly mean flows from the mean of all the monthly mean flows were computed and normalized (rescaled) by the standard deviation of the monthly mean flows. Cumulative values of the rescaled departures were plotted as a function of time to visualize trends in flows. During extended periods of above average flow, the cumulative departures increase with time (positive slope), whereas during extended periods of below average flow, the cumulative departures decrease with time (negative slope). (Plots of cumulative departures are analogous to mass diagrams for reservoir storage. Periods of increasing and decreasing values of the cumulative departures are respectively analogous to periods of increasing and decreasing reservoir storage.)

Statistical Analysis of Long-Term Trends

For this study, long-term trends in annual flows were tested using an extension of the seasonal Mann-Kendall test (Hirsch and Slack, 1984) that accounts for 1-year serial correlation (Appendix C). The Mann-Kendall test (see for example Kendall, 1970; Helsel and Hirsch, 1992) is a nonparametric rank-based test that is resistant to the effects of outlier values and commonly is used for analysis of hydrologic data (see for example Hirsch and Slack, 1984; Lins and Slack, 1999; Douglas and others, 2000; Zhang and others, 2001). In general, the Mann-Kendall test is used to determine whether values of one variable, *y*, tend to increase or decrease as the values of a second variable, *x*, increase or decrease. If *y* increases as *x* increases (either linearly or nonlinearly), the two variables possess a monotonic correlation. If the variable *x* represents time, the Mann-Kendall test can be used to determine whether upward or downward monotonic trends exist in the variable *y*, which may represent streamflow or rainfall for example.

For hydrologic time-series data, the Mann-Kendall test is best suited to analysis of long-term data sets. Although the

Mann-Kendall test can be applied to short time series with less than 10 data values, tests applied to short time series may not provide information that is of practical importance. Tests applied to short time series may (1) fail to detect a statistically significant trend even though a large increase or decrease in flow has occurred, or (2) detect a statistically significant trend even though the trend is of no practical importance.

As an example of the failure of the Mann-Kendall test to detect a statistically significant trend in a short time series even though an important increase or decrease in flow has occurred, consider the average flows in 5 consecutive years of 10, 50, 100, 101, and 99 cubic feet per second. The Mann-Kendall test would not detect a significant trend (5-percent level of significance) for this short time series even though the flows increased considerably after the second year.

As an example of how the Mann-Kendall test could detect a statistically significant trend in a short time series even though the trend is of no practical importance, consider the average flows in 13 consecutive years of 100, 90, 80, 70, 60, 61, 62, 63, 64, 50, 40, 30, and 20 cubic feet per second. Over the 5 central years, the flows increased from 60 to 64 cubic feet per second. The Mann-Kendall test would indicate a statistically significant upward trend (5-percent level of significance) over the 5 central years of the 13-year period even though the flows generally decreased over the entire 13-year period. Over the entire 13-year period, a statistically significant downward trend (5-percent level of significance) would be detected with the Mann-Kendall test.

Serial correlation commonly exists in hydrologic time series and may confound detection of trends. Yue and Wang (2002) indicated that the effect of serial correlation on detection of trends with the Mann-Kendall test is dependent on sample size, magnitude of serial correlation, and magnitude of trend. If the Mann-Kendall test is used to detect trends in a time series with positive serial correlation, a statistically significant trend may be detected even though no trend exists; if the Mann-Kendall test is used to detect trends in a time series with negative serial correlation, no trend may be detected even though a trend does exist (Yue and Wang, 2002). Hirsch and Slack (1984) developed an extension of the Mann-Kendall test for seasonal data with serial dependence. The seasonal Mann-Kendall test developed by Hirsch and Slack (1984) was modified for use in this study to account for serial correlation in annual time series (see Appendix C).

A measure of the strength of the correlation between two variables is provided by Kendall's tau coefficient, which takes on values ranging from -1 to +1. A tau value of -1 indicates that all *y* values decrease with increasing *x*; a tau value of +1 indicates that all *y* values increase with increasing *x*.

The Kendall-Theil robust line is a robust, nonparametric estimate of the slope of a linear trend line relating two variables (see for example Helsel and Hirsch, 1992, p. 266). The nonparametric estimate of the slope is equal to the median of the slopes between all possible pairs of data. Determination of the statistical significance of the slope of the Kendall-Theil robust line is identical to the determination of the statistical significance of Kendall's tau (see Appendix C). For this study, a 5-percent level of significance was selected to indicate whether a statistically significant trend in annual mean flows and annual rainfall exists.

Analysis of the Relation Among Flow, Southern Oscillation Index, and Pacific Decadal Oscillation

Data from the long-term-trend stations (table 1) were analyzed to determine the relation among streamflow in Hawaii and regional indices of interannual climate variability, as measured by the SOI, and interdecadal climate variability, as measured by the PDO index (Mantua and others, 1997). The Mann-Kendall test was used to estimate the correlation between 3-month average flows and lagged 3-month average SOI. Relations were evaluated separately for periods when positive and negative PDO phases were predominant.

Long-Term Trends in Flow

Annual mean, Q_{10}, Q_{25}, Q_{50} (median), Q_{75}, and Q_{90} flows (total flow and base flow), and annual minimum and maximum consecutive 1-, 7-, and 30-day mean total flows (figs. A1–A16) at 16 long-term stations were analyzed for trends during four periods of different lengths: water years 1913–2002, 1933–2002, 1953–2002, and 1973–2002. For each period, only stations with complete data in at least 80 percent of the years were used. Of the long-term-trend stations, only one station (16587000, Honopou Stream near Huelo, Maui) had a complete water year of data prior to water year 1913. Thus, the period 1913 to 2002 was selected as the longest period for which trends in flows were computed. Shorter, more recent periods, were selected to evaluate trends during subsets of the 1913 to 2002 period.

The magnitude and direction of trends in streamflow were determined using the normalized slope of the Kendall-Theil robust line. Slopes of the Kendall-Theil robust line (tables 2-5) were normalized (divided) by the long-term-flow values associated with each slope. For example, dividing the slope value for annual median flow by the overall median flow during the period for which the slope was computed normalized the slope of the trend in annual median flow. For this report, slopes of the Kendall-Theil robust line have units of cubic feet per second per year, whereas normalized slopes have units of year^{-1}.

Water Years 1913–2002

For the 90-year period 1913–2002, data from seven stations, including, one station on Kauai (16068000), two stations on Oahu (16200000 and 16229000), one station on Molokai (16400000), and three stations on Maui (16508000, 16587000 and 16620000), were used to evaluate trends in flow. Mean annual rainfall on the drainage basins above these gaging stations ranges from about 80 to 250 in. (table 1) (Giambelluca and others, 1986).

Cumulative departures of monthly mean base flows for the seven stations (16068000, 16200000, 16229000, 16400000, 16508000, 16587000, and 16620000) generally indicate increasing values of cumulative departures from 1913 to the early 1940s, followed by generally decreasing values to 2002 (fig. 4). Thus, monthly mean base flows generally were above the long-term average from 1913 to the early 1940s and below average after the early 1940s to 2002. The cumulative departures for monthly mean base flows generally are consistent with the trends in annual mean base flow for 1913–2002 described below. At some stations, the patterns of cumulative departures for monthly mean total flow (fig. 4) are similar to those for base flow, particularly for station 16229000 on Oahu. At other stations (for example station 16068000 on Kauai), the patterns of cumulative departures for monthly mean total flow and monthly mean base flow differ. Differing patterns of cumulative departures for total and base flows may reflect different factors controlling the high and low flows at some sites and the different time scales over which these factors vary. In general, base flow is controlled by ground-water storage and does not respond as quickly to changes in rainfall as direct runoff.

For 1913–2002, trends in annual total-flow percentiles at the seven stations generally were downward (fig. 5, table 2). At most stations, trends in the median and lower flows, as indicated by the annual Q_{50}, Q_{75}, and Q_{90} total flows, were statistically significant at the 5-percent level of significance. Trends in the higher flows, as indicated by the annual Q_{10}, Q_{25}, and mean total flows, also generally were downward, although the trends were statistically significant (5-percent level of significance) at only one (16229000) of the seven stations. Trends in the median and lower total flows are consistent with the statistically significant downward trends in annual base-flow percentiles at all seven stations (fig. 6), as well as the statistically significant downward trends in minimum 1-, 7-, and 30-day mean flows at five of the seven stations (fig. 7).

Trends in flows generally reflect statewide trends in rainfall. Statistically significant trends in annual rainfall predominantly indicate decreasing rainfall for the period 1913 to 2001 (fig. 8). Of the 20 statistically significant trends in annual rainfall, 17 are downward, which is consistent with the downward trends in flows at the seven stream-gaging stations during the period.

To determine whether the downward trends in rainfall extend to the period before 1913, annual rainfall data for the period 1893 to 2001 were analyzed (fig. 9). The period 1893 to 2001 was selected because it includes the 20-year period prior to 1913 and because annual rainfall data were available from more than 20 stations. From 1893 to 2001, only three significant trends in annual rainfall were detected at the 23 stations evaluated. Statistically significant downward trends in annual rainfall were detected at two sites in northeastern Maui; a statistically significant upward trend was detected at one site near the northern part of the island of Hawaii. Thus, although rainfall trends commonly were downward during the 89-year period from 1913 to 2001, over the 109-year period 1893 to 2001, significant trends were much less common.

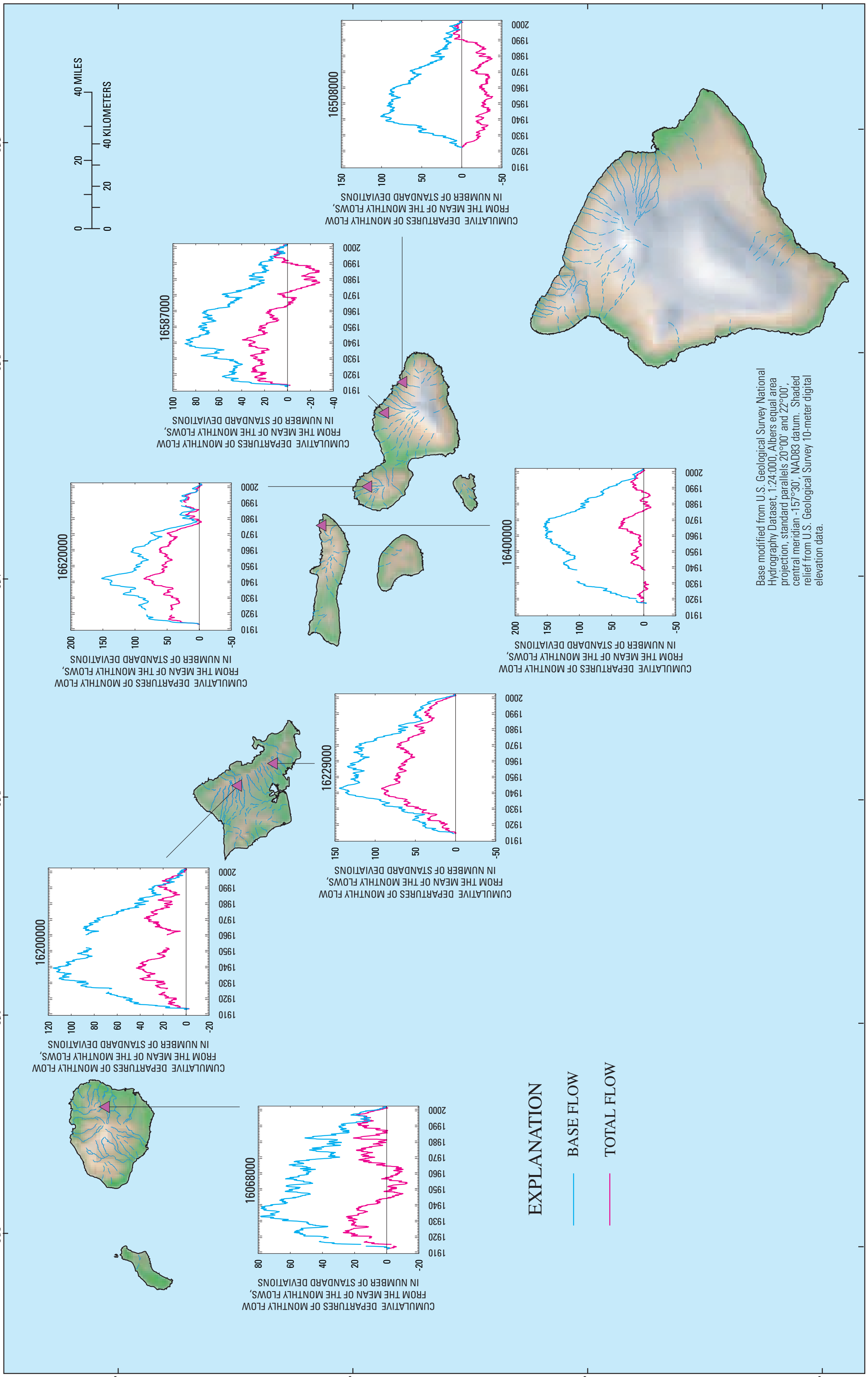

Figure 4. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii (based on complete water years from 1913 through 2002).

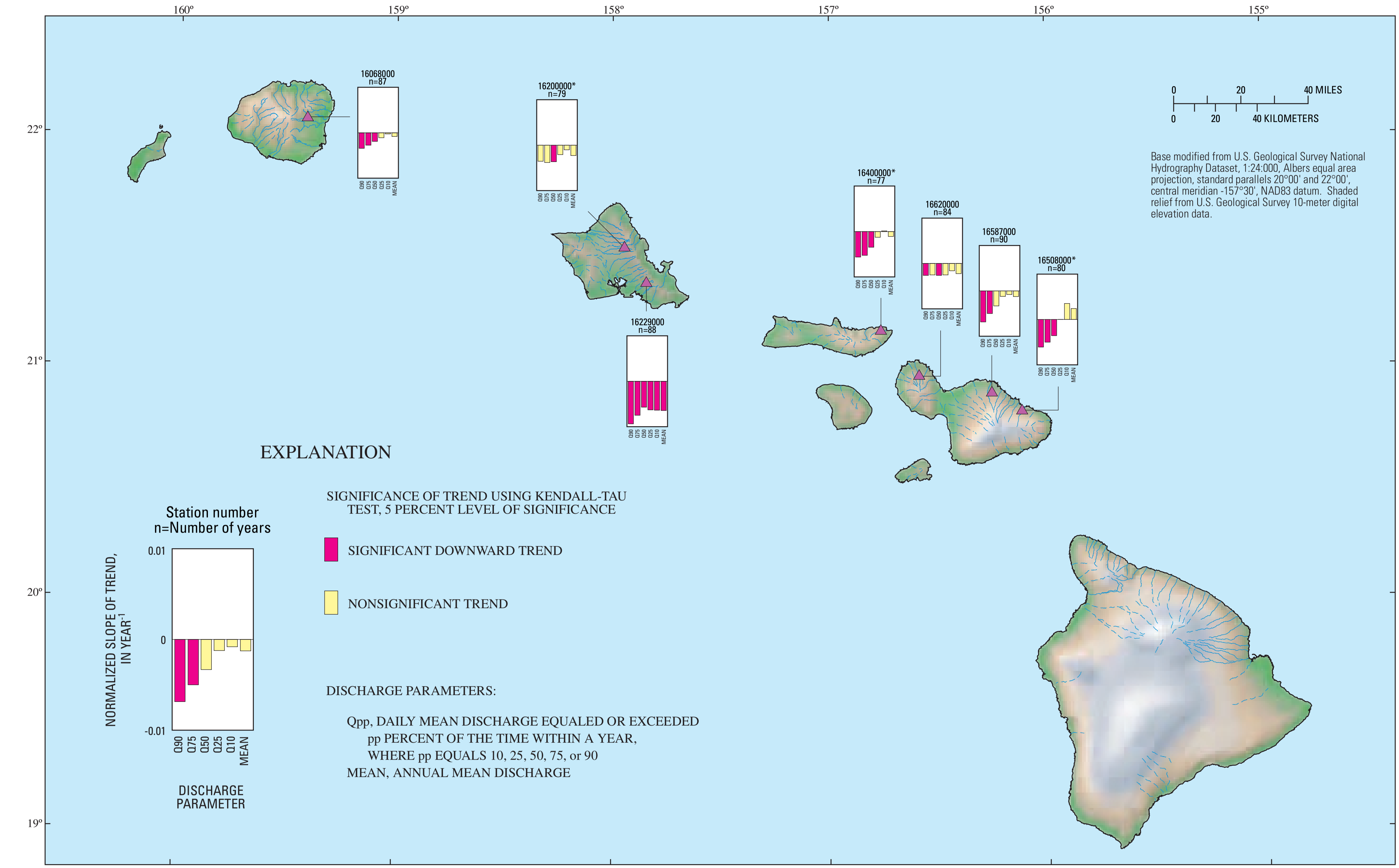

Figure 5. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (total streamflow) during 1913–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1913–1942, 1943–1972, and 1973–2002.

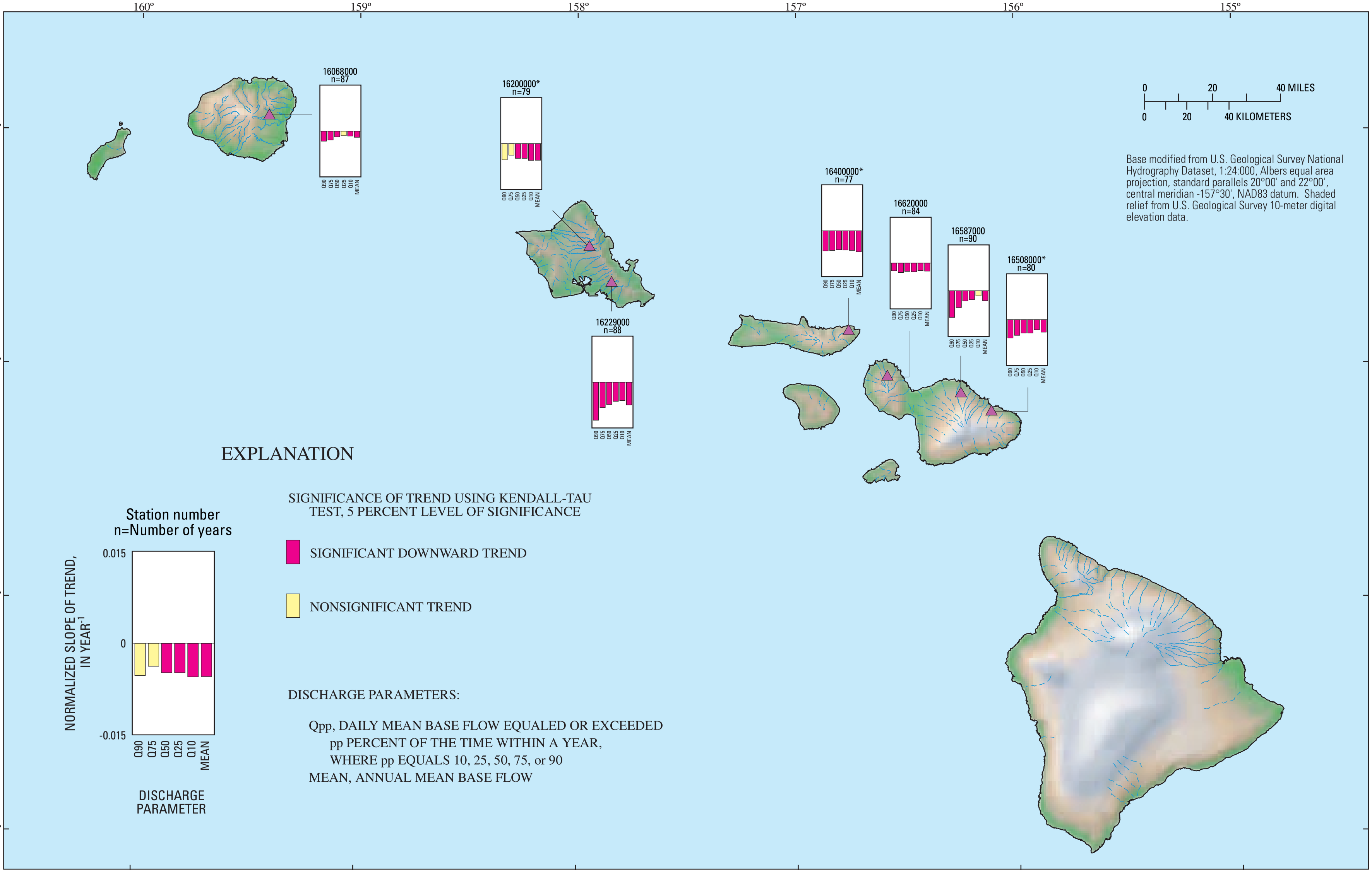

Figure 6. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (base flow) during 1913–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1913–1942, 1943–1972, and 1973–2002.

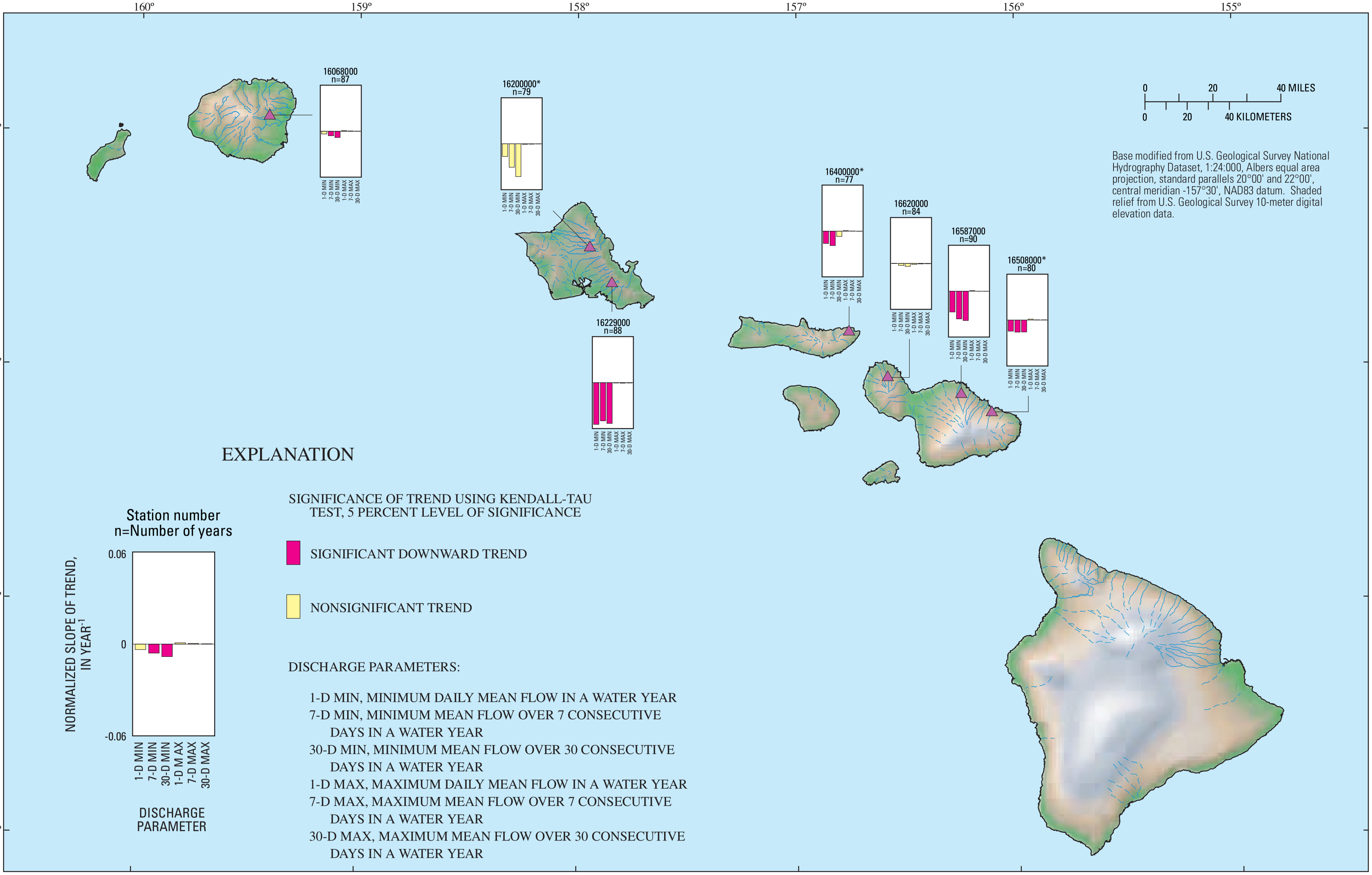

Figure 7. Trends in annual 1-, 7-, and 30-day minimum and maximum flows (total streamflow) during 1913–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1913–1942, 1943–1972, and 1973–2002.

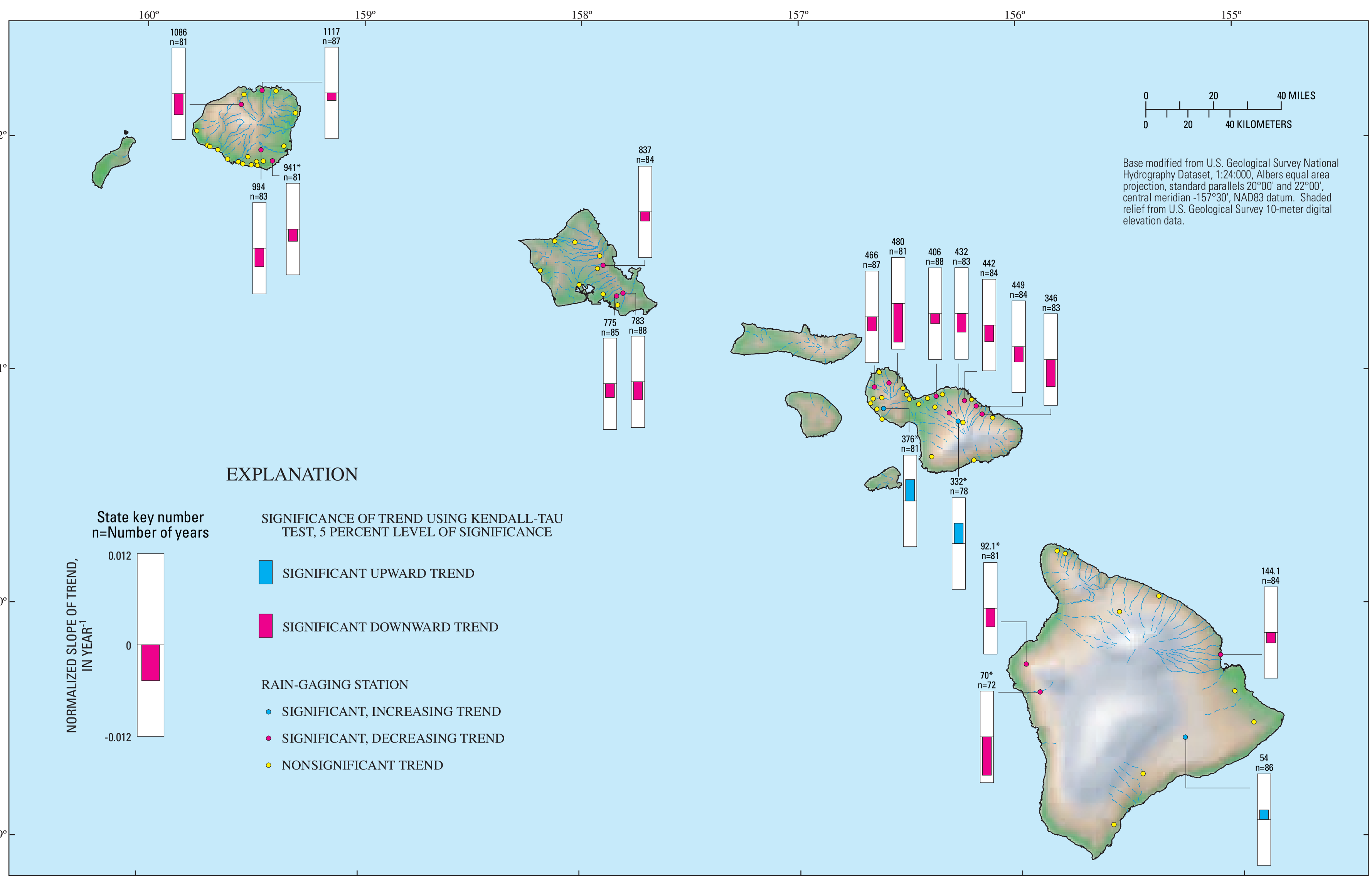

Figure 8. Trends in annual rainfall during 1913–2001, State of Hawaii. Indicated slopes are normalized by dividing by the mean annual rainfall during the specified period. Stations shown have annual-rainfall values (calendar year) for at least 80 percent of the years over the indicated period. All stations with significant trends (except those indicated with an asterisk) also have annual-rainfall values for at least 80 percent of the years during each of the periods 1913–1942, 1943–1972, and 1973–2001.

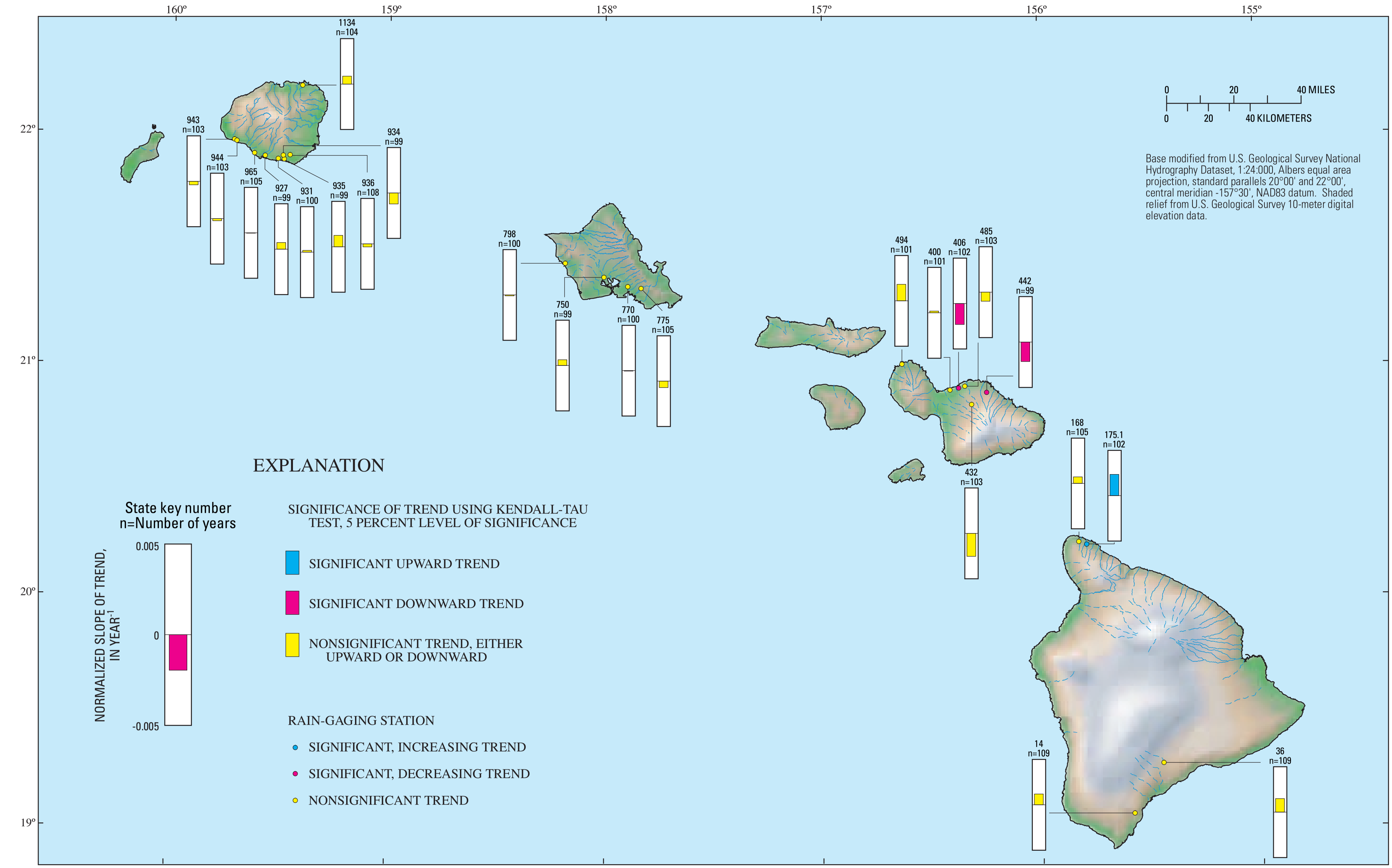

Figure 9. Trends in annual rainfall during 1893–2001, State of Hawaii. Indicated slopes are normalized by dividing by the mean annual rainfall during the specified period. Stations shown have annual-rainfall values (calendar year) for at least 90 percent of the years over the indicated period.

Water Years 1933–2002

For the 70-year period 1933–2002, data from seven stations, including one station on Kauai (16068000), two stations on Oahu (16200000 and 16229000), one station on Molokai (16400000), and three stations on Maui (16508000, 16587000, and 16620000), were used to evaluate trends in flow. Mean annual rainfall on the drainage basins above these gaging stations ranges from about 80 to 250 in. (table 1) (Giambelluca and others, 1986).

For stations 16229000 on Oahu and 16400000 on Molokai, cumulative departures of monthly mean base flows generally increased from 1933 to about 1970 and decreased after 1970 (fig. 10). Thus, for these two stations, monthly mean base flows generally were above average from 1933 to about 1970 and below average after 1970. For station 16508000 on Maui, cumulative departures of monthly mean base flows increased from 1933 to about 1940 and decreased after about 1960. The pattern of cumulative departures of monthly mean total flows and monthly mean base flows are similar at stations 16229000 and 16620000, but differ at stations 16508000 and 16587000.

For the period 1933–2002, trends in the annual total-flow percentiles at the seven stations generally were downward (fig. 11, table 3), although statistically significant downward trends in total-flow percentiles were detected at only four of the seven stations (stations 16229000 on Oahu, 16400000 on Molokai, and 16508000 and 16587000 on Maui). The statistically significant downward trends in annual total-flow percentiles generally were for the median and lower flows (Q_{50}, Q_{75}, and Q_{90}). No significant upward trends in annual total-flow percentiles were detected.

For the period 1933-2002, trends in the annual base-flow percentiles at the seven stations generally were downward (fig. 12, table 3), and statistically significant downward trends in base-flow percentiles were detected at five of the seven stations. At stations 16229000 (Oahu) and 16400000 (Molokai), statistically significant downward trends were detected in all measured base-flow percentiles, ranging from annual Q_{10} to Q_{90} base flows. At the three other stations with statistically significant downward trends in annual base-flow percentiles, the downward trends were restricted to narrower flow ranges. Statistically significant downward trends in base-flow percentiles were detected at station 16200000 on Oahu (Q_{10} base flow), station 16508000 on Maui (Q_{75} and Q_{90} base flows), and station 16587000, also on Maui (Q_{90} base flow).

Statistically significant downward trends were detected in the 1-, 7-, and 30-day mean minimum flows at stations 16508000 and 16587000 on Maui (fig. 13). Trends in the 1-, 7-, and 30-day mean minimum flows at other stations were downward but not statistically significant at the 5-percent level. Statistically significant upward trends in the 1- and 7-day mean maximum flows at station 16068000 on Kauai were detected (fig. 13), which may reflect a trend toward the occurrence of more intense storms over time within the drainage basin of this station. A statistically significant downward trend in the 30-day mean maximum flow at station 16229000 on Oahu also was detected, although the normalized slope of the trend is small.

For the period 1933–2001, statistically significant trends in annual rainfall were detected at 14 stations (fig. 14). Statistically significant downward trends in annual rainfall were detected at 12 of the 14 sites, and statistically significant upward trends in annual rainfall were detected at only two sites, both on Maui.

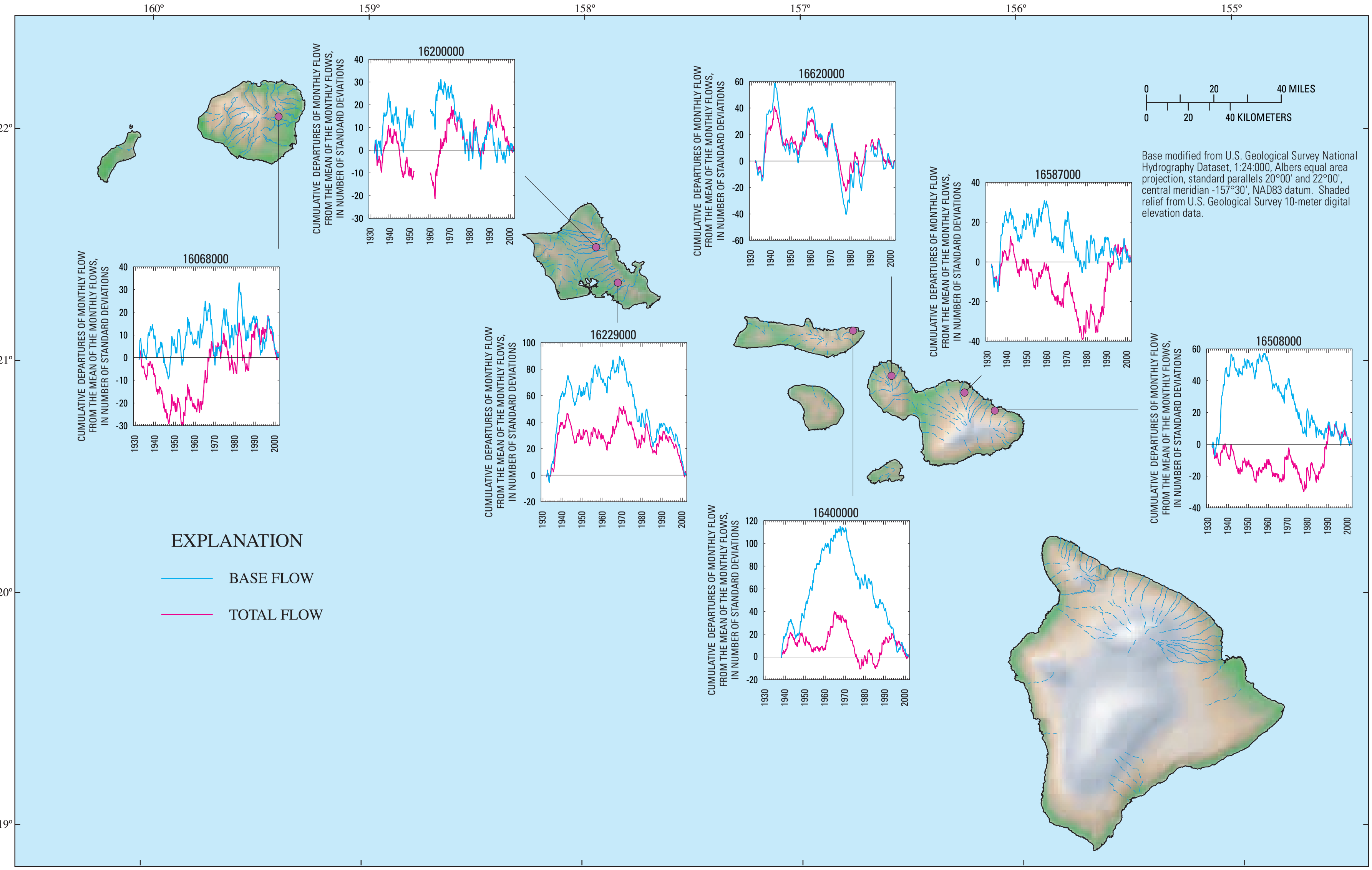

Figure 10. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii (based on complete water years from 1933 through 2002).

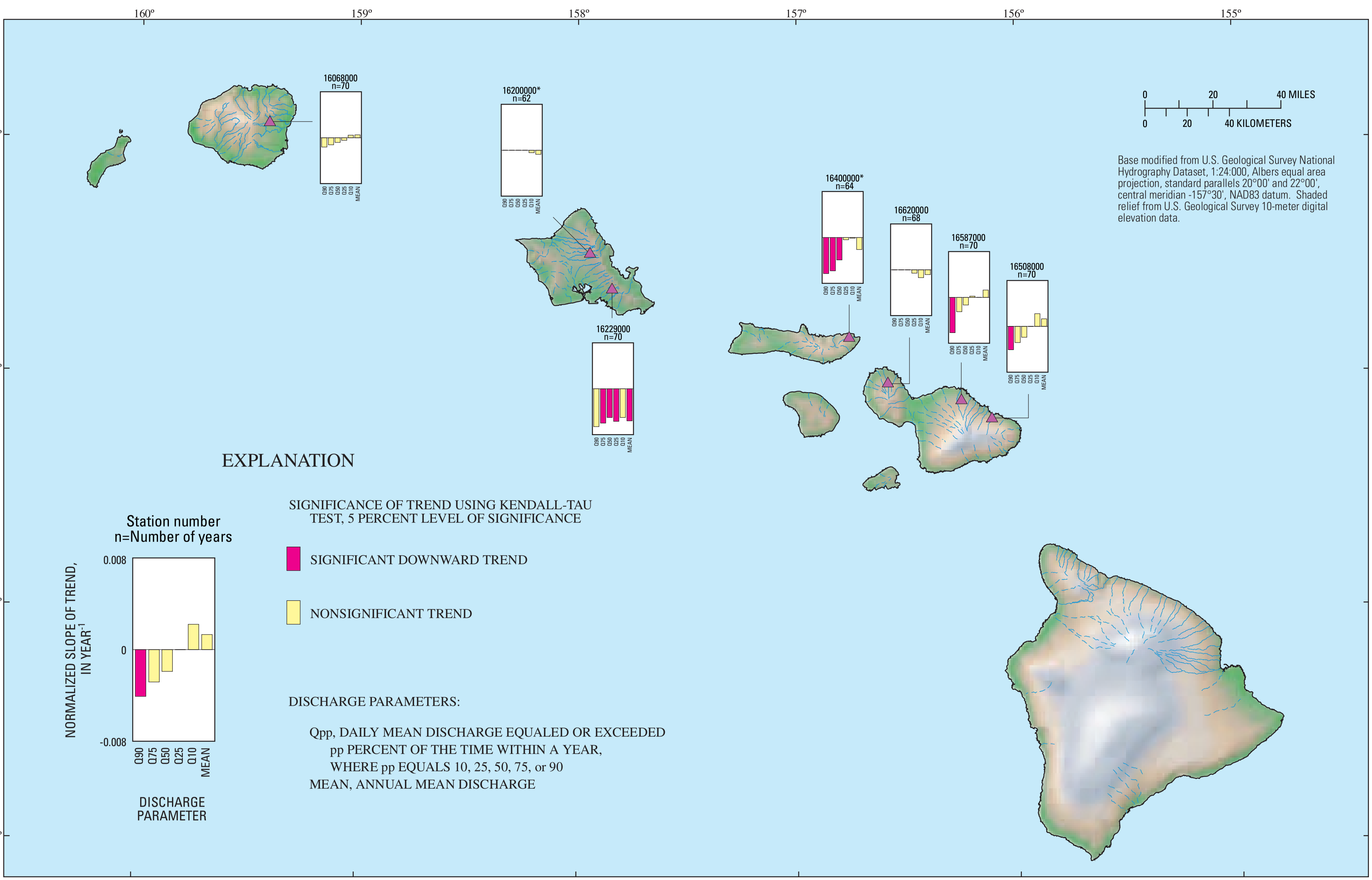

Figure 11. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (total streamflow) during 1933–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1933–1955, 1956–1978, and 1979–2002.

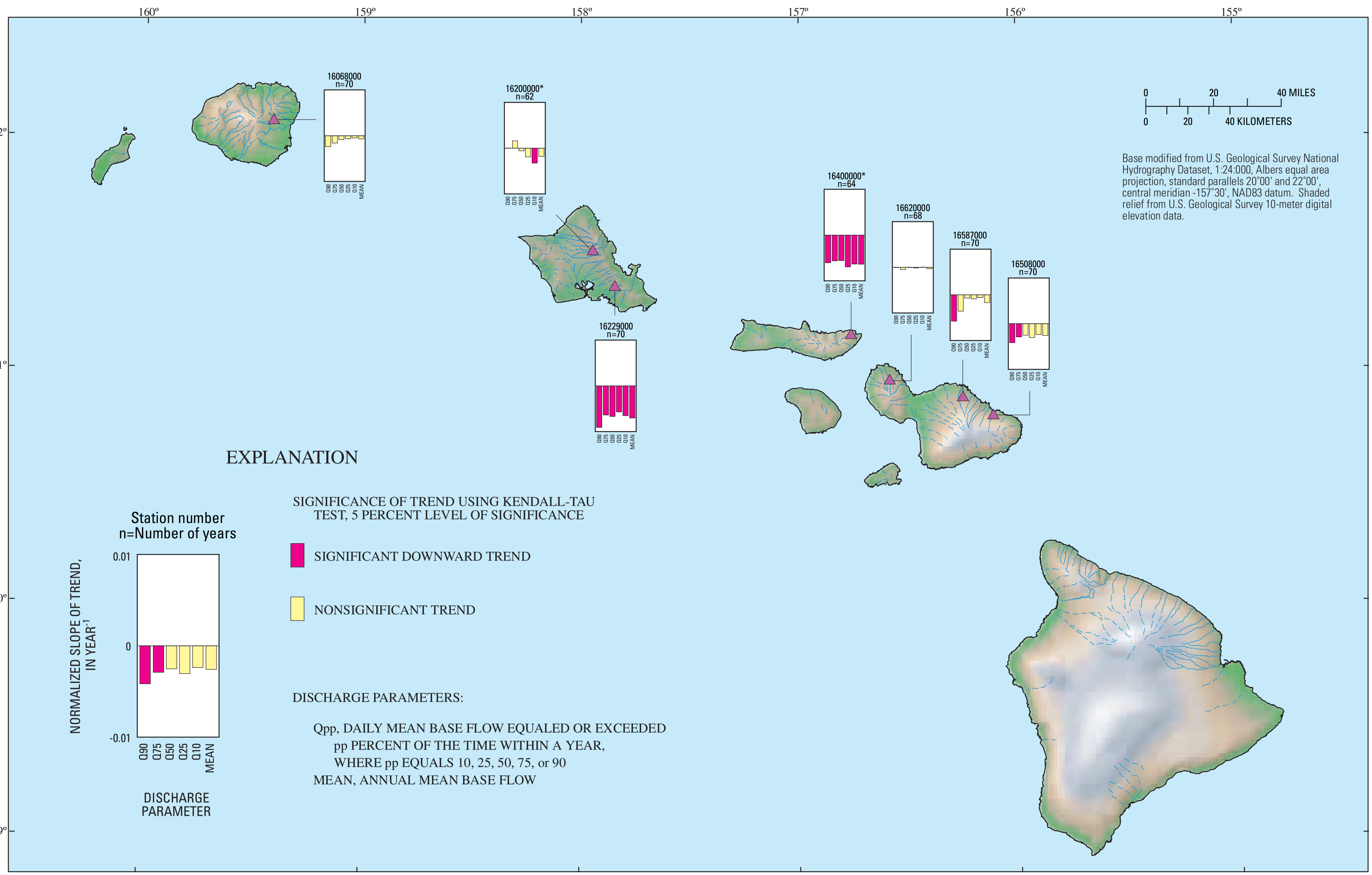

Figure 12. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (base flow) during 1933–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1933–1955, 1956–1978, and 1979–2002.

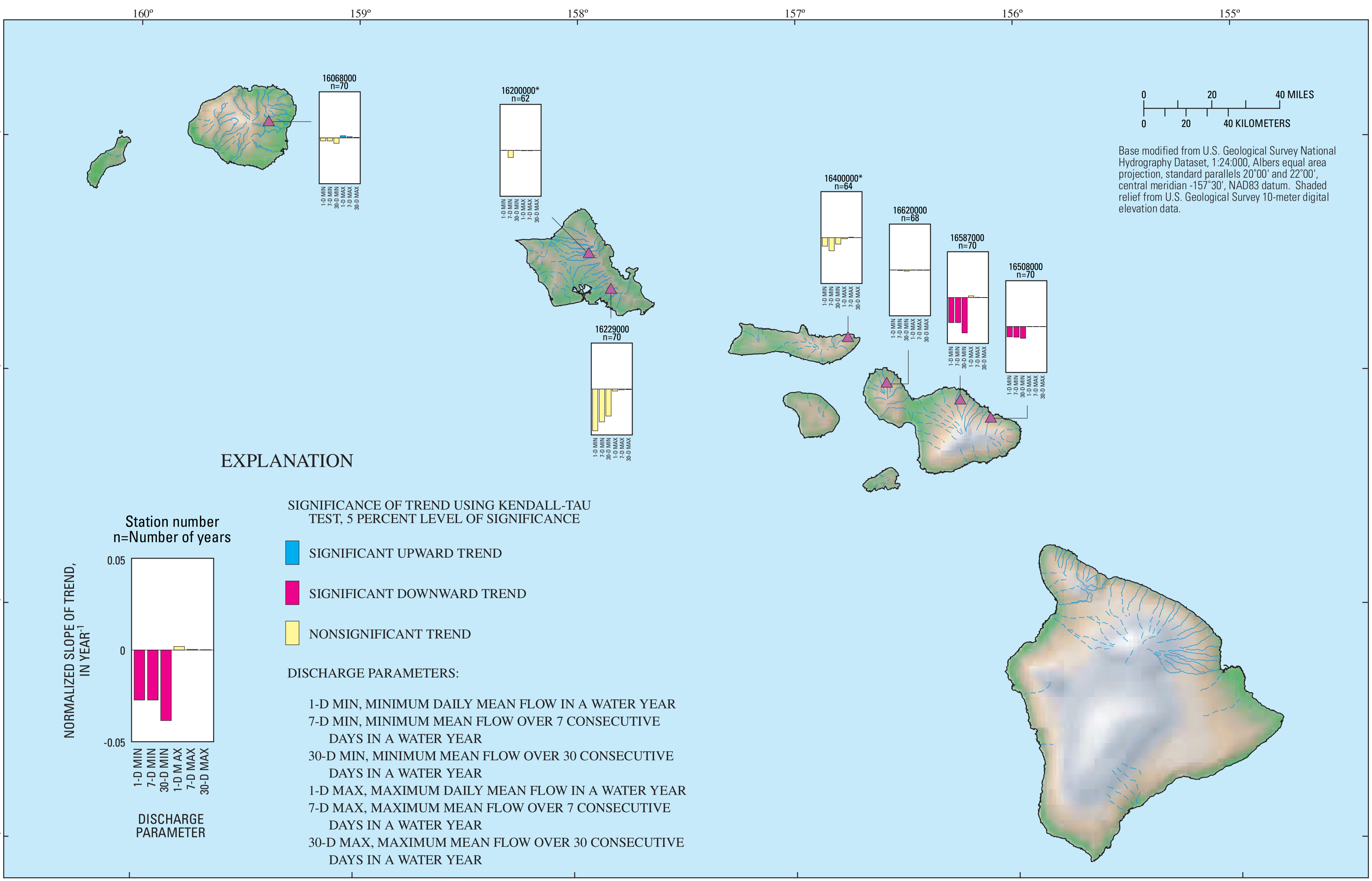

Figure 13. Trends in annual 1-, 7-, and 30-day minimum and maximum flows (total streamflow) during 1933–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1933–1955, 1956–1978, and 1979–2002.

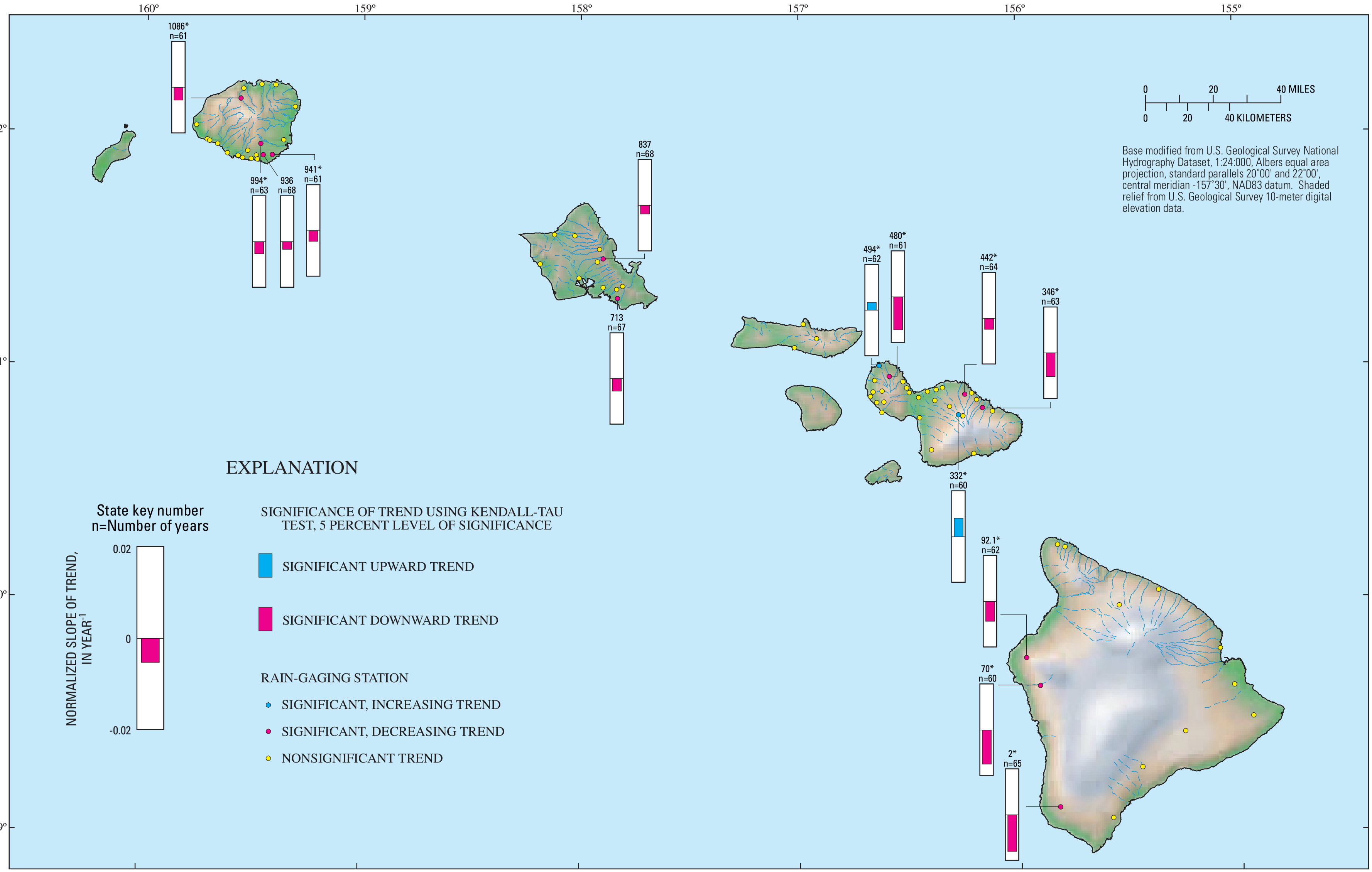

Figure 14. Trends in annual rainfall during 1933–2001, State of Hawaii. Indicated slopes are normalized by dividing by the mean annual rainfall during the specified period. Stations shown have annual-rainfall values (calendar year) for at least 80 percent of the years over the indicated period. All stations with significant trends (except those indicated with an asterisk) also have annual-rainfall values for at least 80 percent of the years during each of the periods 1933–1955, 1956–1978, and 1979–2001.

Water Years 1953–2002

For the 50-year period 1953–2002, data from 14 stations, including four stations on Kauai (16019000, 16068000, 16097500, and 16108000), five stations on Oahu (16200000, 16211600, 16226000, 16229000, and 16303003), one station on Molokai (16400000), and four stations on Maui (16508000, 16587000, 16618000, and 16620000) were used to evaluate trends in flow. Mean annual rainfall on the drainage basins above these gaging stations ranges from about 70 to 260 in. (table 1) (Giambelluca and others, 1986).

For station 16211600 on Oahu, the cumulative departures of monthly total and base flows generally increased from about the early 1960s to the early 1990s and decreased after the early 1990s. Thus, for station 16211600, monthly mean total and base flows generally were above average from the early 1960s to the early 1990s and below average after the early 1990s. For station 16400000 on Molokai, cumulative departures of monthly mean base flows generally increased from 1953 to about 1970 and decreased after 1970 (fig. 15), indicating that monthly mean base flows generally were above average from 1953 to about 1970 and below average after 1970. For station 16019000 on Kauai, the cumulative departures of monthly total and base flows increased from about the early 1960s to the early 1980s and decreased after the early 1980s (fig. 15). However, prior to the early 1960s, the pattern of cumulative departures at station 16019000 is less clear.

For the period 1953–2002, statistically significant downward trends in annual total-flow characteristics were only detected at station 16211600 on Oahu (Q_{10} and mean total flow) (fig. 16, table 4). However, statistically significant downward trends in annual base-flow percentiles were detected at five stations (fig. 17). At station 16400000 (Molokai), statistically significant downward trends in the median and higher base flows (Q_{50}, Q_{25}, Q_{10}, and mean) were detected. Statistically significant downward trends in annual base-flow percentiles also were detected at Oahu stations 16211600 (Q_{10} and Q_{25} base flow), 16226000 (Q_{10} base flow), 16229000 (Q_{10} base flow), and 16303003 (Q_{25} base flow).

Statistically significant downward trends were detected in the 1-day mean maximum flows at three stations on Oahu (16200000, 16226000, and 16229000), which may reflect a trend toward smaller storms over time within the drainage basins of these stations (fig. 18). In addition, statistically significant downward trends were detected in the 7-day mean maximum flows at two stations on Oahu (16226000 and 16229000), and statistically significant downward trends were detected in the 30-day mean maximum flows at four stations on Oahu (16200000, 16211600, 16226000, and 16229000). No other statistically significant trends were detected in the 1-, 7-, and 30-day mean minimum and maximum flows.

For the period 1953–2001, all 16 statistically significant trends detected in annual rainfall were downward (fig. 19).

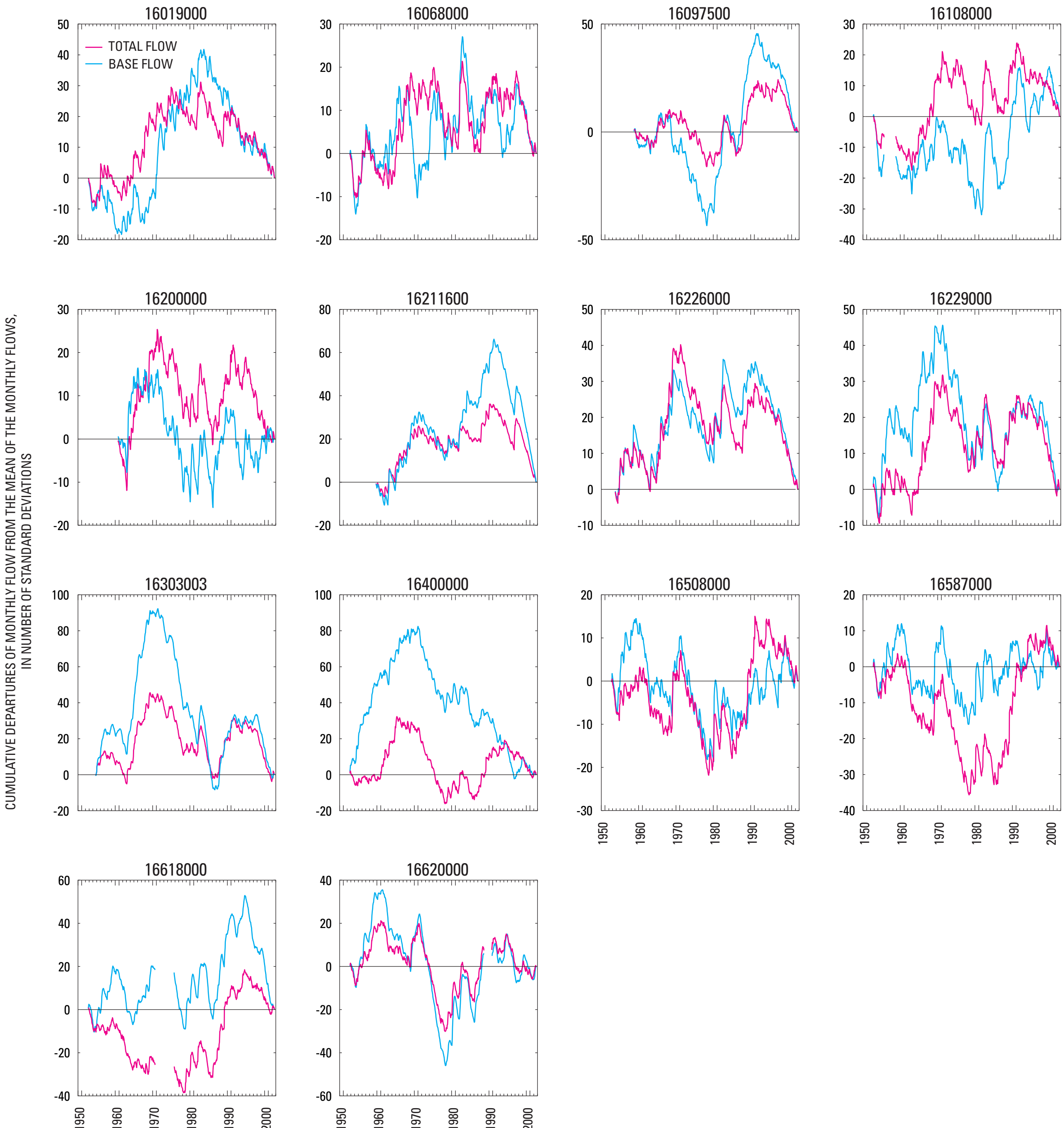

Figure 15. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii (based on complete water years from 1953 through 2002). See figure 1 for station locations.

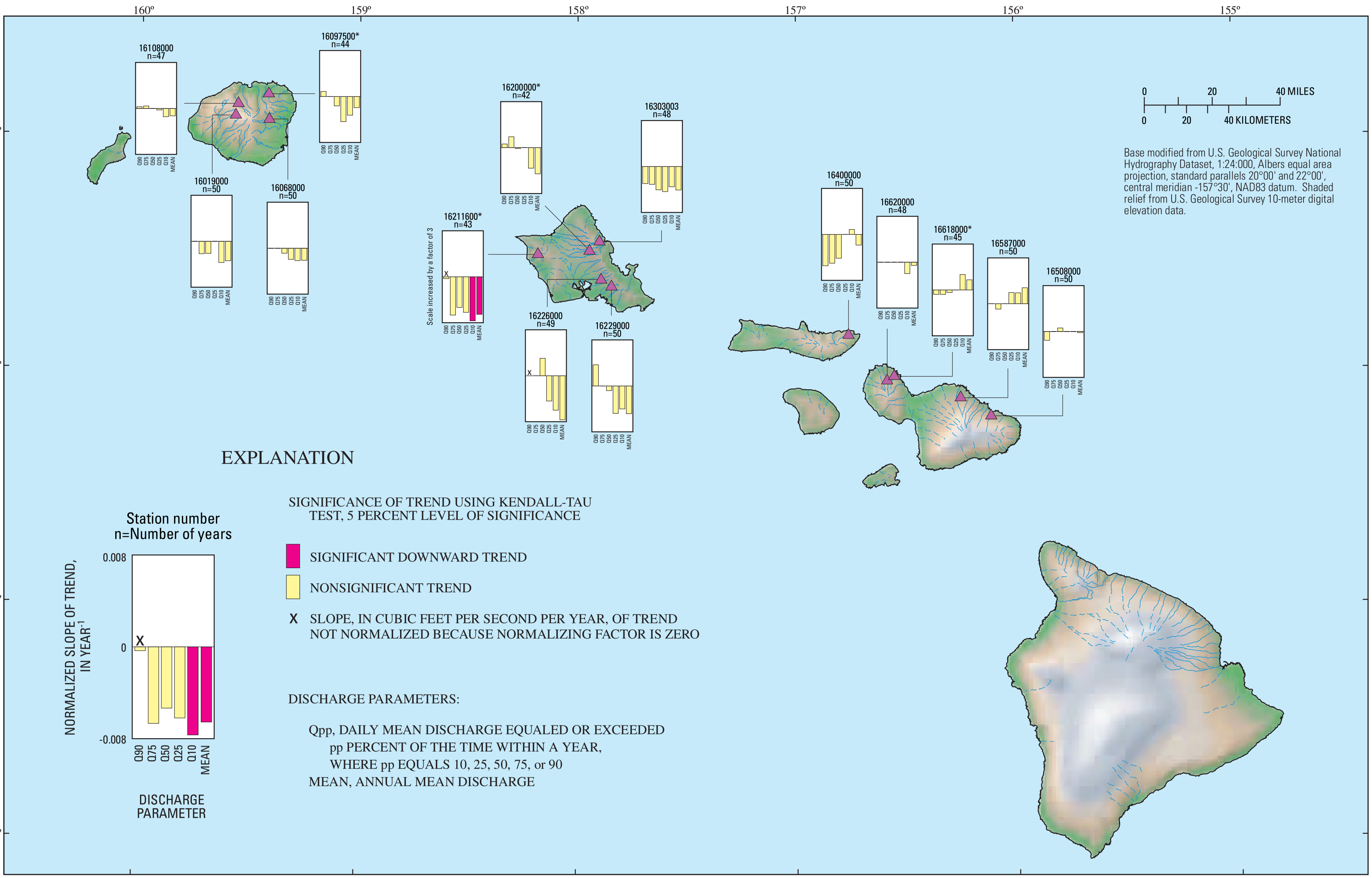

Figure 16. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (total streamflow) during 1953–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1953–1968, 1969–1985, and 1986–2002.

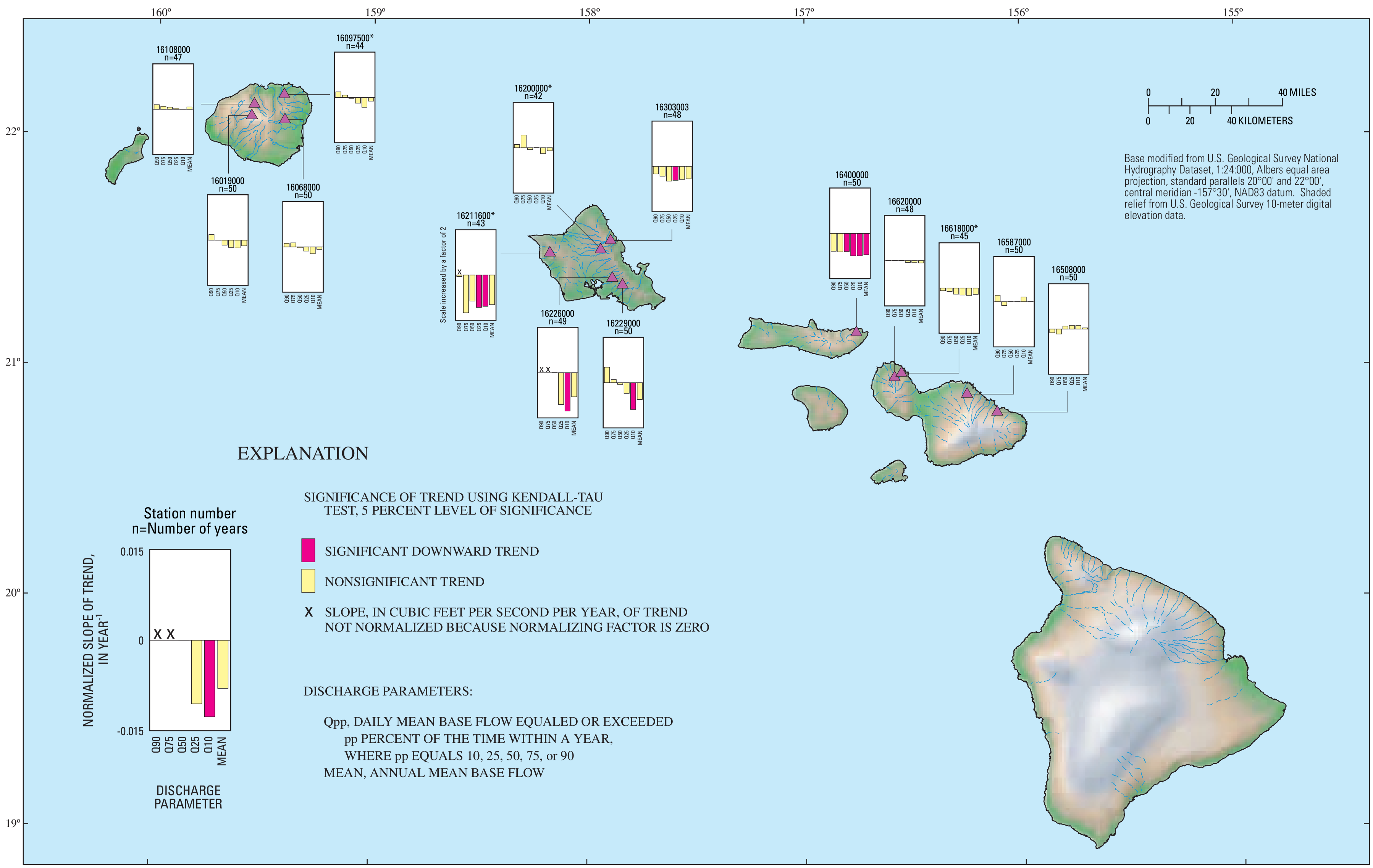

Figure 17. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (base flow) during 1953–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1953–1968, 1969–1985, and 1986–2002.

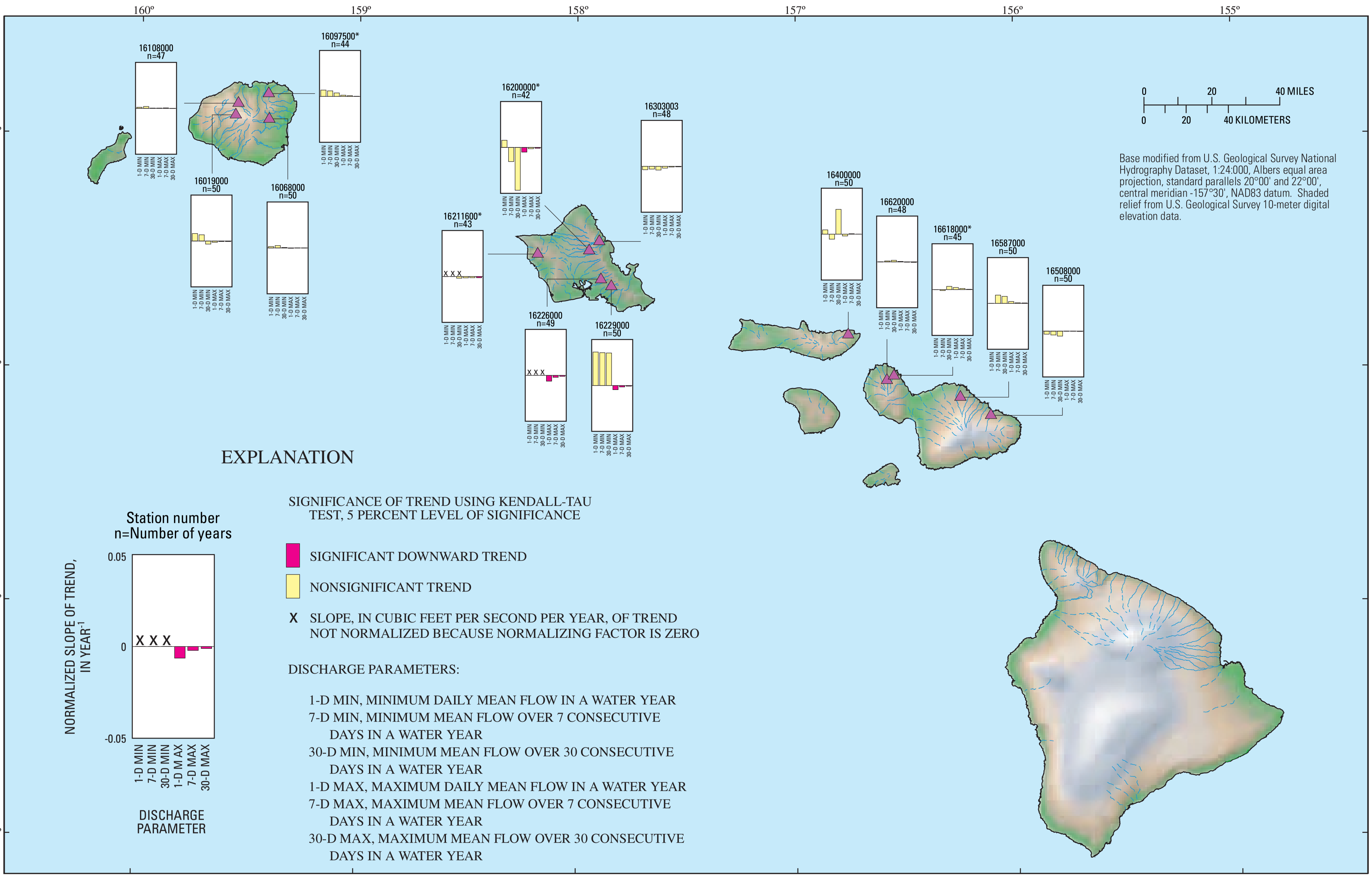

Figure 18. Trends in annual 1-, 7-, and 30-day minimum and maximum flows (total streamflow) during 1953–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1953–1968, 1969–1985, and 1986–2002.

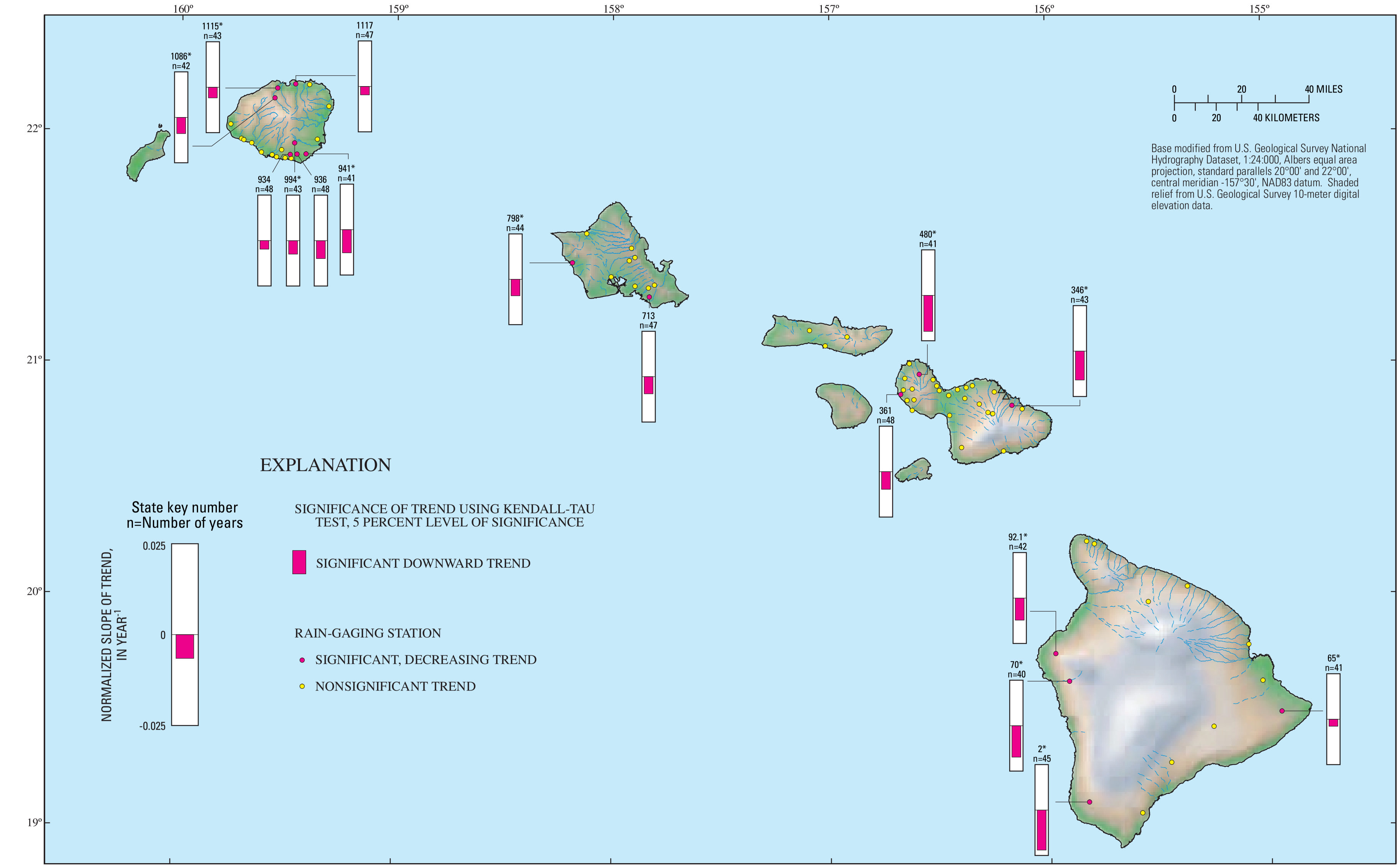

Figure 19. Trends in annual rainfall during 1953–2001, State of Hawaii. Indicated slopes are normalized by dividing by the mean annual rainfall during the specified period. Stations shown have annual-rainfall values (calendar year) for at least 80 percent of the years over the indicated period. All stations with significant trends (except those indicated with an asterisk) also have annual-rainfall values for at least 80 percent of the years during each of the periods 1953–1968, 1969–1985, and 1986–2001.

Water Years 1973–2002

For the 30-year period 1973–2002, data from 16 stations, including four stations on Kauai (16019000, 16068000, 16097500, and 16108000), five stations on Oahu (16200000, 16211600, 16226000, 16229000, and 16303003), one station on Molokai (16400000), four stations on Maui (16508000, 16587000, 16618000, and 16620000), and two stations on the island of Hawaii (16717000 and 16720000), were used to evaluate trends in flow. Mean annual rainfall on the drainage basins above these gaging stations ranges from about 70 to 260 in. (table 1) (Giambelluca and others, 1986).

For most of the long-term-trend stations, cumulative departures of monthly flows generally indicate below average flows during the 1970s. For station 16019000 on Kauai, the cumulative departures of monthly base flows generally increased from 1973 to the early 1980s and decreased after the early 1980s (fig. 20). Thus, for station 16019000, monthly mean base flows generally were above average from 1973 to the early 1980s and below average from the early 1980s to 2002. For station 16211600 on Oahu, the cumulative departures of monthly base flows increased after about 1980 until the early 1990s and generally decreased after the early 1990s (fig. 20).

For the period 1973–2002, a statistically significant downward trend in the total flow Q_{10} was detected at station 16211600 on Oahu (fig. 21, table 5). A statistically significant upward trend in the total flow Q_{25} was detected at station 16717000 on the island of Hawaii (fig. 21). No other statistically significant trends for annual total-flow percentiles were detected.

Statistically significant downward trends in annual base-flow percentiles were detected at three stations in the north-western part of the State: station 16211600 on Oahu (Q_{75} base flow), station 16097500 on Kauai (Q_{10} base flow), and station 16019000 on Kauai (Q_{10}, Q_{25}, and mean base flow) (fig. 22, table 5). A statistically significant upward trend in the Q_{10} base flow was detected near the southeastern part of the State at station 16720000 on the island of Hawaii (fig. 22).

Statistically significant upward trends were detected in the 1-day mean minimum flow at station 16019000 on Kauai, and in the 1- and 7-day mean minimum flows at station 16229000 on Oahu (fig. 23). No other statistically significant trends were detected in the 1-, 7-, and 30-day mean minimum and maximum flows.

For the period 1973–2001, statistically significant downward trends in annual rainfall were detected at only three stations (one station each near the southern parts of the islands of Kauai, Oahu, and Hawaii) (fig. 24). No statistically significant upward trends in annual rainfall were detected in the State at the stations considered.

Figure 20. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii (based on complete water years from 1973 through 2002). See figure 1 for station locations.

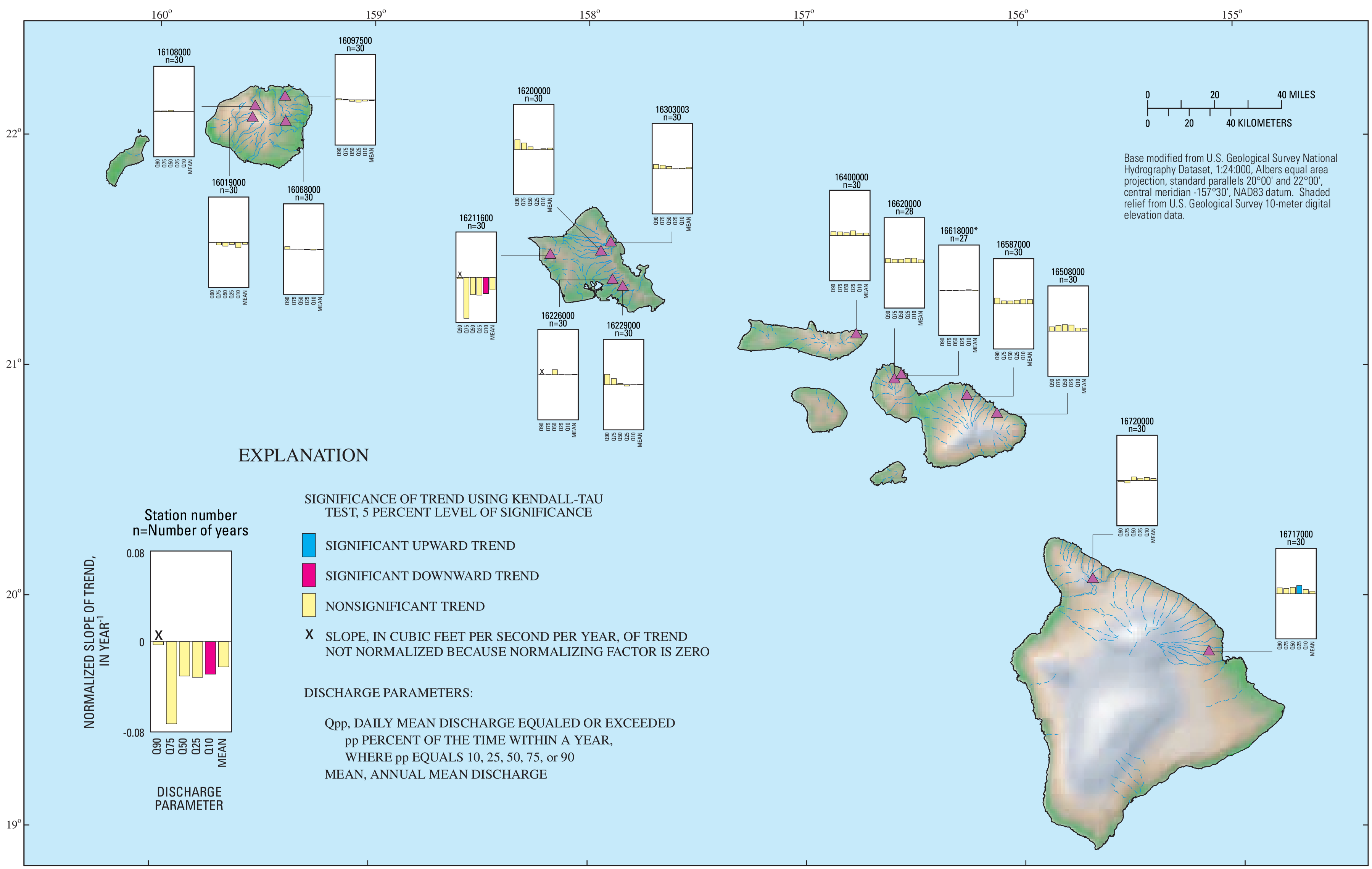

Figure 21. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (total streamflow) during 1973–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1973–1982, 1983–1992, and 1993–2002.

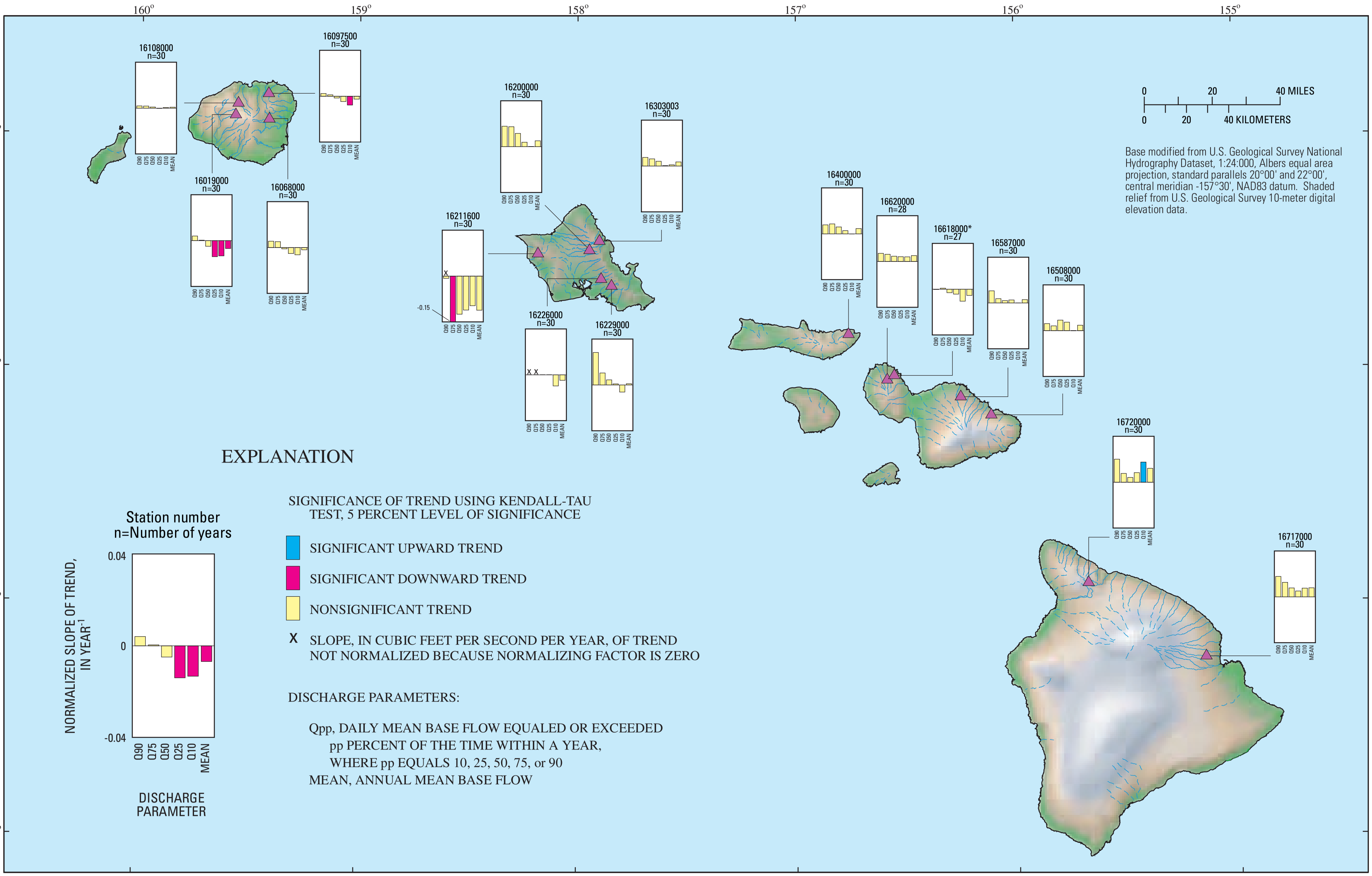

Figure 22. Trends in annual mean and 10-, 25-, 50-, 75-, and 90-percentile flows (base flow) during 1973–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1973–1982, 1983–1992, and 1993–2002.

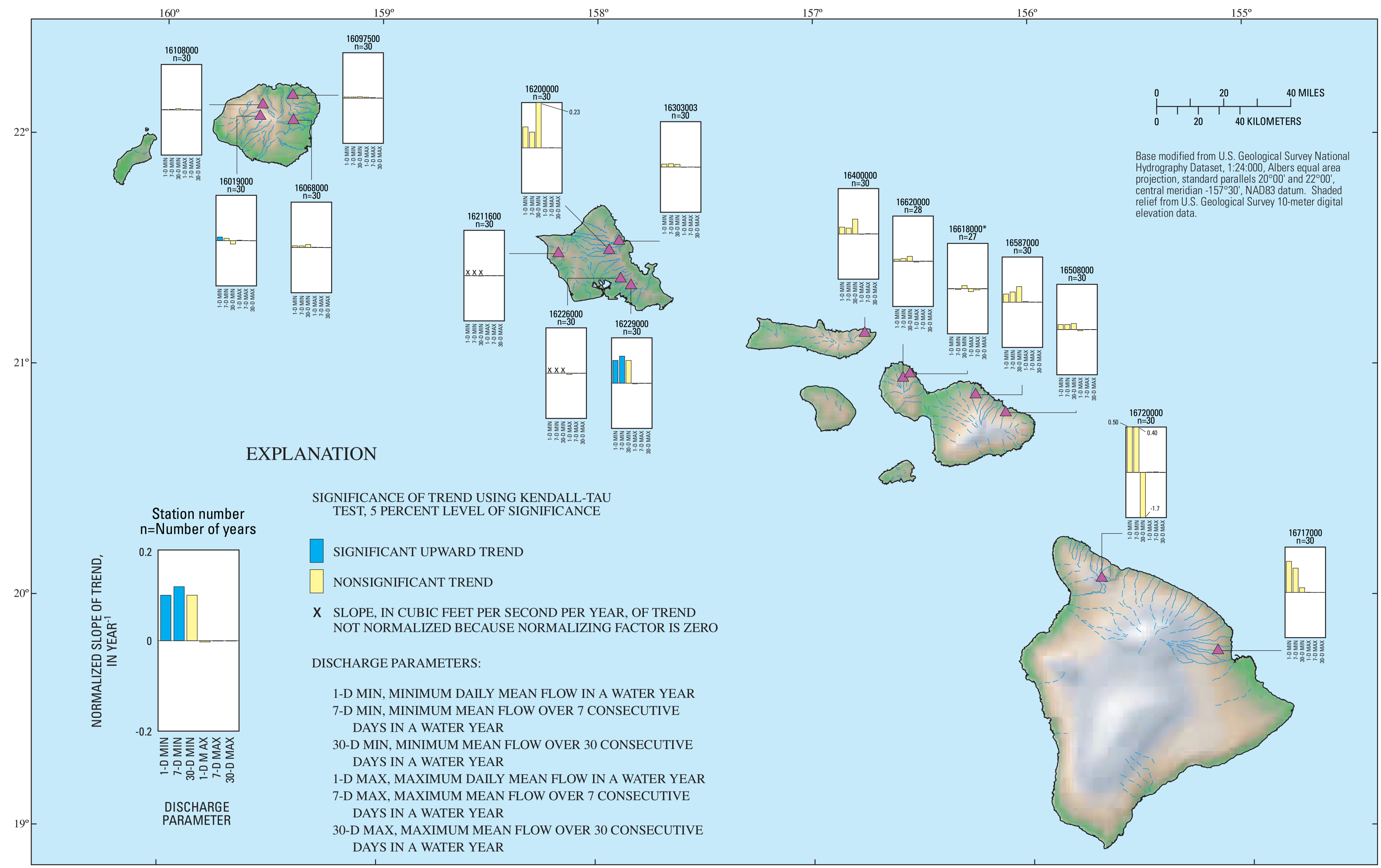

Figure 23. Trends in annual 1-, 7-, and 30-day minimum and maximum flows (total streamflow) during 1973–2002, State of Hawaii. Indicated slopes are normalized by dividing each parameter slope for a station by the overall period value for that parameter and station. Flow parameters are computed using daily mean discharge values for each water year with complete record. The record for each station shown contains data with complete water years (not necessarily consecutive) for at least 80 percent of the total number of water years during the indicated period. All stations (except those indicated with an asterisk) also have complete data for at least 80 percent of the water years during each of the periods 1973–1982, 1983–1992, and 1993–2002.

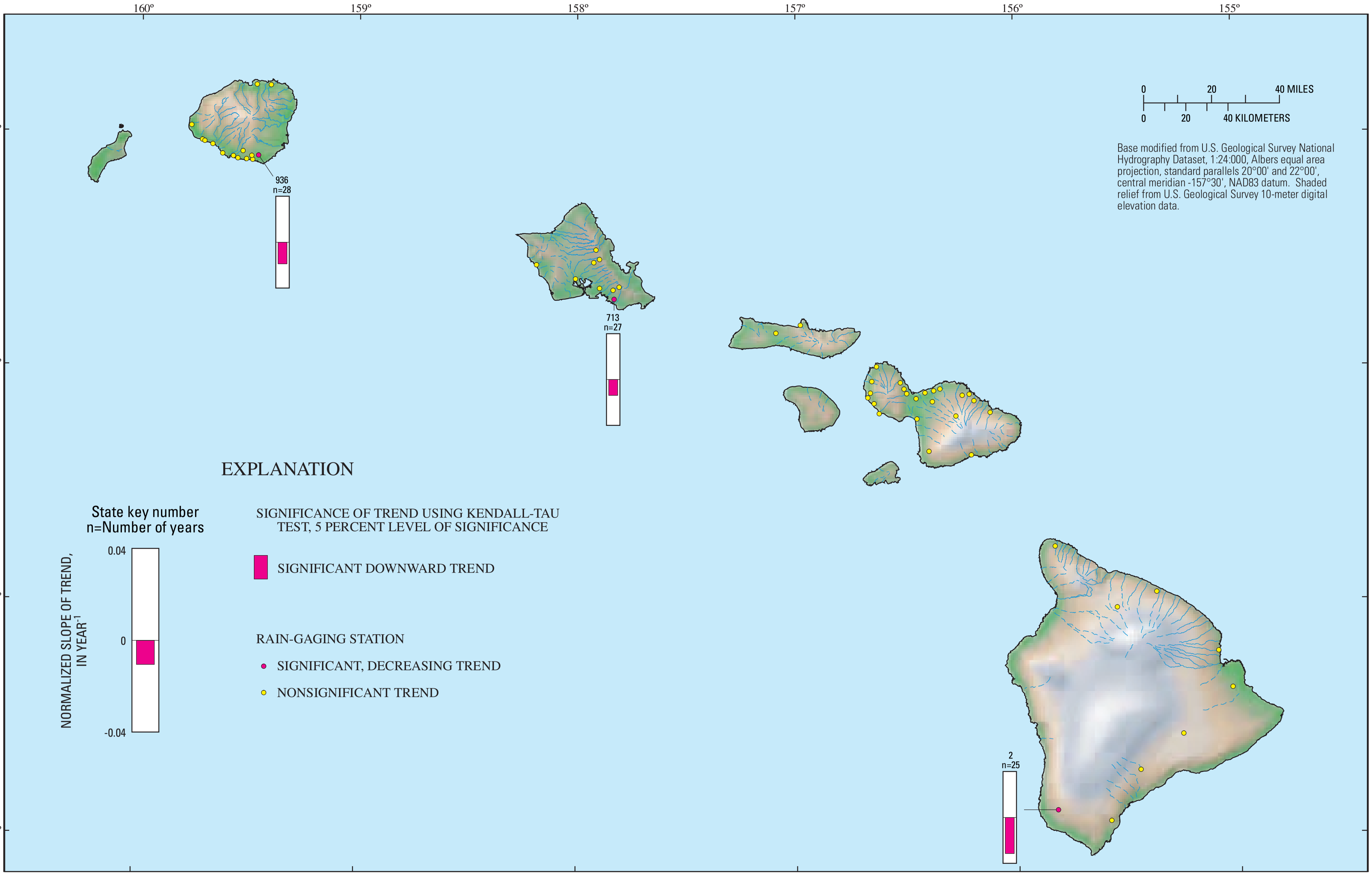

Figure 24. Trends in annual rainfall during 1973–2001, State of Hawaii. Indicated slopes are normalized by dividing by the mean annual rainfall during the specified period. Stations shown have annual-rainfall values (calendar year) for at least 80 percent of the years over the indicated period. All stations with significant trends also have annual-rainfall values for at least 80 percent of the years during each of the periods 1973–1982, 1983–1992, and 1993–2001.

Summary of Patterns in Long-Term Trends

Data are available from seven long-term-trend stations on four islands since 1913. Data from these seven stations indicate that low flows generally decreased from 1913 to 2002, and this trend is consistent with the long-term downward trend in rainfall over much of the State during the period. Thus, the long-term downward trend in low flows at the seven long-term-trend stations may be representative of conditions throughout much of the State from 1913 to 2002.

Long-term downward trends in low flows of streams may indicate a reduction in ground-water discharge to streams caused by a long-term decrease in ground-water storage and recharge. Because ground water provides about 99 percent of Hawaii's domestic drinking water (Gingerich and Oki, 2000), a reduction in ground-water storage and recharge has serious implications for drinking-water availability. In addition, reduction in stream base flows may affect habitat availability for native stream fauna and water availability for irrigation purposes. Thus, identifying and understanding the causes of trends in streamflow is essential for proper water management.

Cumulative-departure graphs (fig. 4) indicate above average base flows during the period from about 1913 to the early 1940s and below average base flows from the early 1940s to 2002, and this pattern is consistent with the measured downward trends in base flows from 1913 to 2002. Although trends in rainfall and low flows in streams commonly were downward during the 90-year period 1913 to 2002, significant trends in rainfall during the 109-year period from 1893 to 2001 generally were not detected. Because significant trends in rainfall were not common over the extended period from 1893 to 2001, long-term trends in streamflow also may have been less common during the same period. Further study is needed to determine (1) whether the downward trends in base flows from 1913 to 2002 will continue or whether the observed pattern is part of a long-term cycle in which base flows may eventually return to levels measured during 1913 to the early 1940s, and (2) the physical causes for the trends in streamflow detected for the period 1913 to 2002.

Data are available from seven long-term-trend stations on four islands since 1933. Data indicate that overall trends in low-flow characteristics from 1933 to 2002 generally are downward. However, statistically significant downward trends were not detected at stations on Kauai (16068000) and northwest Maui (16620000) from 1933 to 2002, although statistically significant downward trends in low flows were detected during 1913 to 2002 at these stations. Thus, the period from 1913 to 1933 may have been a period of relatively high flow at these sites, which is consistent with the above average base flows prior to the early 1940s indicated by the cumulative-departure graphs (fig. 4).

From 1953 to 2002 and from 1973 to 2002, the percentage of stations with statistically significant downward trends in low flows decreased relative to the earlier periods (1913 to 2002 and 1933 to 2002). From 1953 to 2002, statistically significant downward trends in base-flow percentiles were detected only at stations on Oahu and eastern Molokai, and from 1973 to 2002, statistically significant downward trends in base-flow percentiles were detected only at stations on Kauai and northwestern Oahu. From 1973 to 2002, statistically significant upward trends in some flow characteristics were detected at stations on Kauai, Oahu, and Hawaii.

The percentage of statistically significant trends in rainfall and flow for the period 1973 to 2002 is much lower than for the period 1913 to 2002. Trends in rainfall and streamflow based on a few decades of data may not be representative of long-term conditions for a given location. Furthermore, detection of patterns in trends over time scales of a few decades may be confounded by high spatial and temporal variability in both rainfall and flow characteristics in Hawaii. Thus, interpretation of trend patterns from short-term rainfall or streamflow records may be uncertain. Over longer time scales, detected trend patterns generally would be more reliable, which underscores the need to maintain a network of long-term-trend stations in Hawaii.

Patterns in long-term trends in rainfall or streamflow may be highly dependent on the time period selected for analysis. For example, if the beginning part of the selected time period is wet and the ending part is dry (such as the period 1913–2002 in Hawaii), then downward trends in rainfall or streamflow may be readily detected. However, if the beginning and ending parts of the selected time period are dry and the middle part is wet (perhaps similar to the period 1893–2001 in Hawaii), then trends in rainfall or streamflow may be less apparent.

Relation Among Streamflow, Southern Oscillation Index, and Pacific Decadal Oscillation

To evaluate the relation among flow and the SOI and PDO index, the correlation between 3-month average flow and 3-month average SOI for monthly lags of -120 to 120 months was estimated using Kendall's tau coefficient (Helsel and Hirsch, 1992). For this report, negative lags correspond to 3-month average flow preceding 3-month average SOI, whereas positive lags correspond to 3-month average SOI preceding 3-month average flow. The 3-month average flows for each complete water year of record from each of the 16 long-term-trend stations were computed for four periods—October to December, January to March, April to June, and July to September. Thus, the average October to December flow was computed for each complete water year of record at each station. Similarly, the average January to March flow, average April to June flow, and average July to September flow also were computed for each complete water year of record at each station.

For each 3-month period, Kendall's tau coefficient relating the 3-month average flow and concurrent 3-month average SOI was computed separately for positive (water years

1925–1946 and 1977–1998) and negative (water years before 1925, 1947–1976, and after 1998) phases of the PDO. In addition, Kendall's tau coefficient relating the 3-month average flow and the 3-month average SOI also was computed for all nonzero monthly lags from -120 to 120 months. For the October to December period of flow, a positive 1-month lag for the SOI would correspond to the 3-month average SOI during September to November of the same year. For the October to December period of flow, a negative 1-month lag for the SOI would correspond to the 3-month average SOI during November and December of the same year and January of the following year. Larger lags were handled similarly.

The relations between flow and SOI are presented in the form of cross-correlograms that show the value of Kendall's tau coefficient at all monthly lags from -120 to 120 months (figs. 25–40). The cross-correlograms show the relations between flow (total flow and base flow) and SOI separately for positive and negative PDO phases and for different 3-month periods of flow. The results presented in the following sections mainly describe overall patterns in the structure of the cross-correlograms rather than the individual cross-correlograms for each station.

January to March

Total Flow, Positive PDO Phase.— During positive PDO phases, statistically significant positive correlation (5-percent level of significance) between average total flow for January to March and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at all 16 of the long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 15 of the 16 stations (fig. 25).

During positive PDO phases, statistically significant positive correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from -2 to 9 months at 15 of the 16 long-term-trend stations, and for at least four lags from 0 to 9 months at 13 of the 16 stations (fig. 25). Thus, total flow during the winter months of January to March tends to be low during or following El Niño (negative-SOI) periods and high during or following La Niña (positive-SOI) periods that occur during positive PDO phases. At station 16618000 in northwestern Maui, average total flow for January to March and 3-month average SOI are positively correlated for lags of -2 to 9 months during positive PDO phases, although the correlation is not statistically significant at the 5-percent level. Also during positive PDO phases, statistically significant positive correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from 60 to 100 months at eight of the 16 long-term-trend stations (including two stations on Kauai, three on Oahu, one on Molokai, and two on Hawaii).

During positive PDO phases, statistically significant negative correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from -11 to -46 months at 12 of the 16 long-term-trend stations (all four stations on Kauai; stations 16211600, 16226000 and 16303003 on Oahu; 16400000 on Molokai; 16508000, 16587000, and 16620000 on Maui; and 16720000 on Hawaii), and for at least two lags from -31 to -46 months at seven of the 16 stations (fig. 25). Also during positive PDO phases, statistically significant negative correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from 13 to 33 months at eight stations (including three stations on Kauai, two on Maui, and one each on Oahu, Molokai, and Hawaii) and for at least one lag from 111 to 120 months at eight stations (including two stations each on Kauai and Oahu, one on Molokai, and three on Maui).

For many of the long-term-trend stations, lags for which the correlation between average total flow and 3-month average SOI is positive and statistically significant are bracketed by lags for which the correlation is negative and statistically significant. In general, the variation in correlation as a function of different lag values is consistent with a quasi-cyclic process. Some of the cross-correlograms (fig. 25) appear to have a quasi-cyclic structure in which the correlation varies from positive to negative to positive with a period of about 4 to 8 years (see for example station 16680000 on Kauai). A 4- to 8-year period may be slightly greater than the period associated with the ENSO cycle.

Total Flow, Negative PDO Phase.— During negative PDO phases, statistically significant positive correlation between average total flow for January to March and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at 15 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 14 of the 16 stations (fig. 26).

During negative PDO phases, statistically significant positive correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from -3 to 8 months at eight of the 16 long-term-trend stations, and for at least two lags from -2 to 8 months at seven of the 16 stations (stations 16019000, 16068000, and 16108000 on Kauai; 16200000, 16226000, and 16229000 on Oahu; and 16400000 on Molokai) (fig. 26). Also during negative PDO phases, statistically significant positive correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from -57 to -86 months at 10 of the 16 stations (16068000, 16097500, and 16108000 on Kauai; all five stations on Oahu; and 16587000 and 16620000 on Maui), and for at least one lag from 51 to 95 months at 12 stations (16068000, 16097500, and 16108000 on Kauai; 16211600, 16226000, and 16303003 on Oahu; 16400000 on Molokai; all four stations on Maui; and 16717000 on Hawaii).

During negative PDO phases, statistically significant negative correlation between average total flow for January to March and 3-month average SOI was detected for at least one lag from -10 to -45 months at nine of the 16 long-term-trend stations, and for at least two lags from -10 to -45 months at

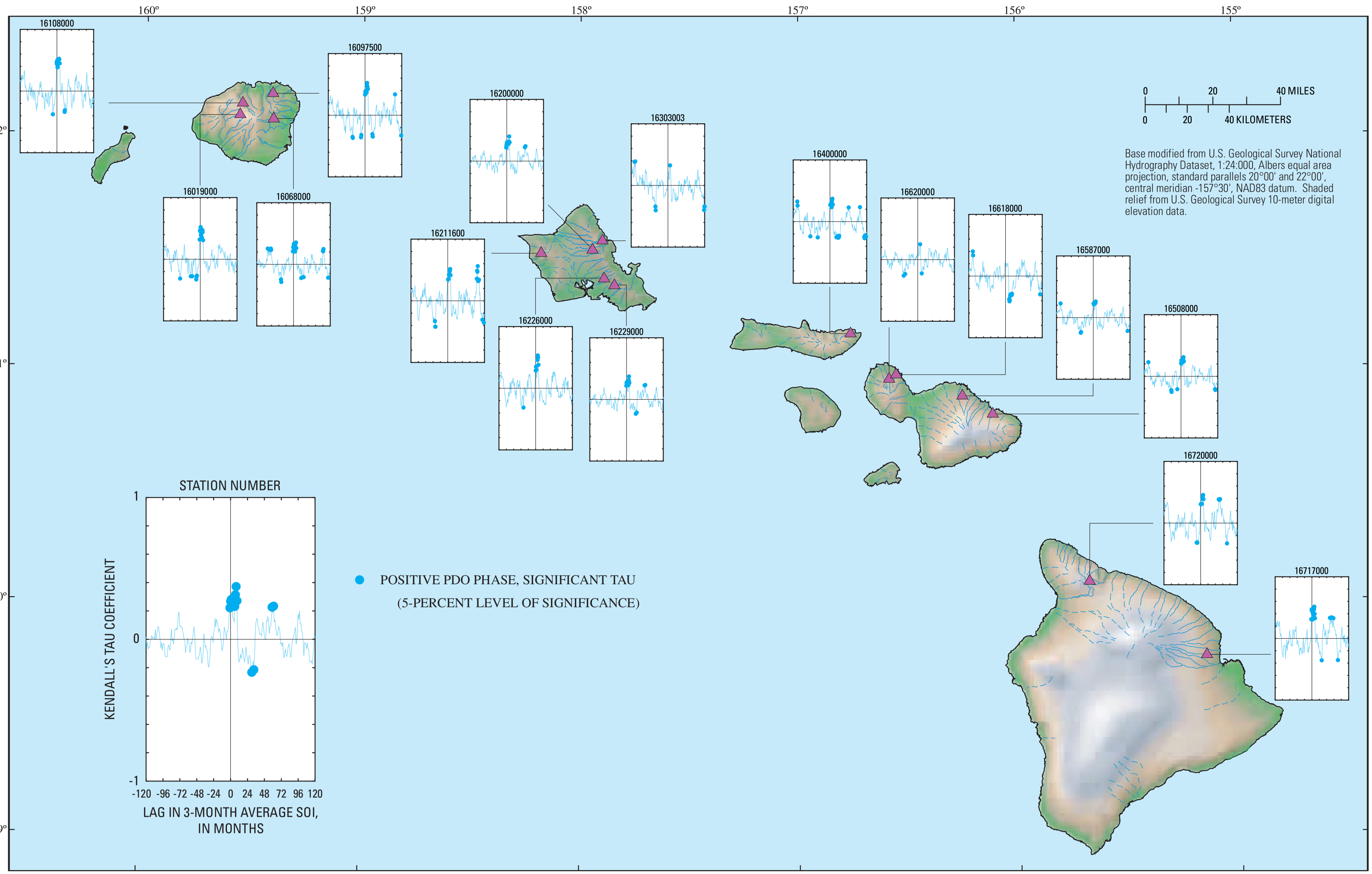

Figure 25. Relation between 3-month (January to March) average total flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

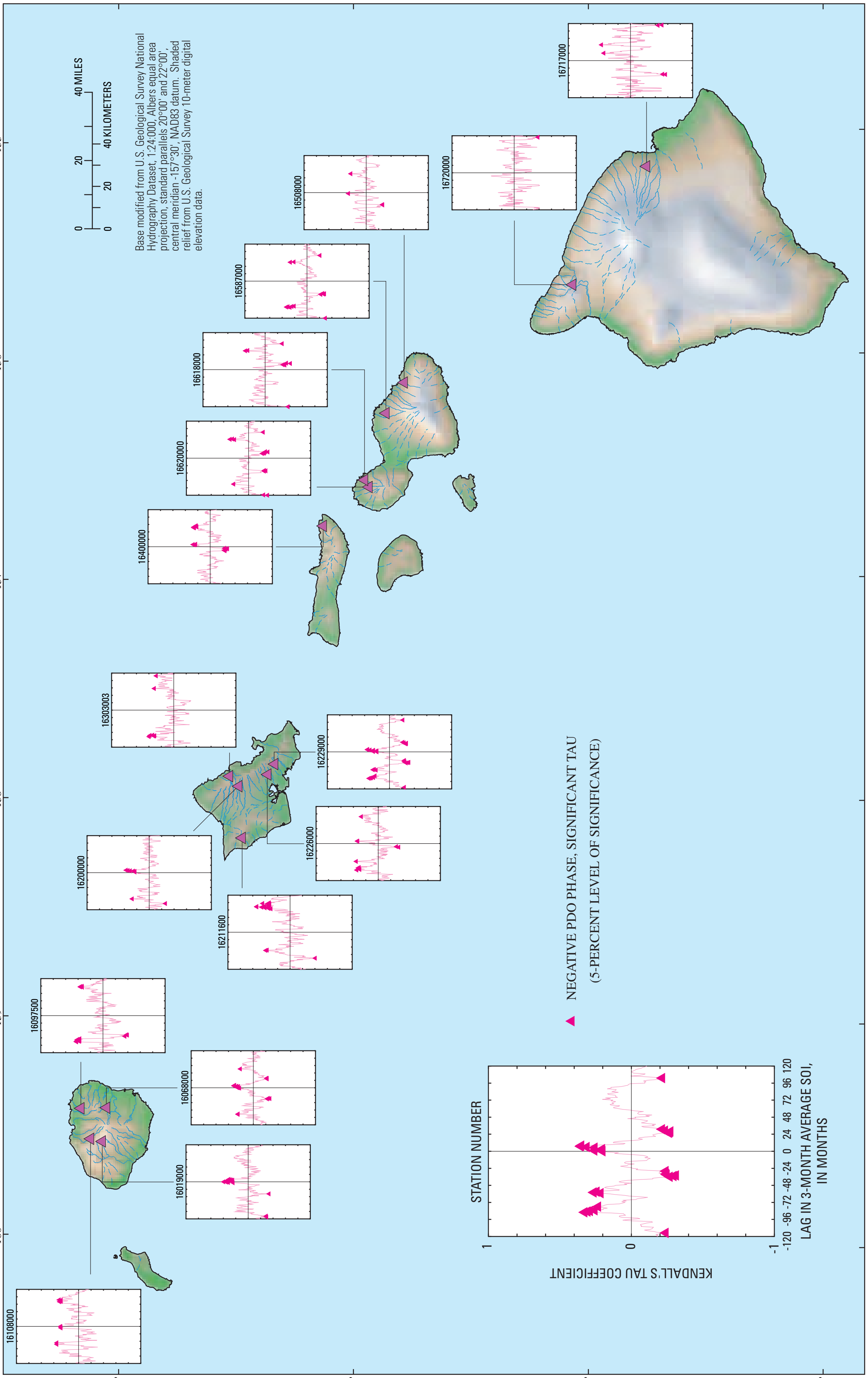

Figure 26. Relation between 3-month (January to March) average total flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

eight of the 16 stations (station 16068000 on Kauai; 16226000 and 16229000 on Oahu; 16400000 on Molokai; 16508000, 16587000, and 16620000 on Maui; and 16717000 on Hawaii) (fig. 26). Also during negative PDO phases, statistically significant negative correlation between average total flow for January to March and 3-month average SOI was detected for at most two lags from -100 to -120 months at six of the 16 stations.

Base Flow, Positive PDO Phase.— During positive PDO phases, statistically significant positive correlation between average base flow for January to March and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at 14 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 15 of the 16 stations (fig. 27).

During positive PDO phases, statistically significant positive correlation between average base flow for January to March and 3-month average SOI was detected for at least four lags from -2 to 9 months at 11 of the 16 long-term-trend stations (fig. 27). At stations 16108000 on Kauai, 16303003 on Oahu, and 16720000 on Hawaii, average base flow during January to March and 3-month average SOI are positively correlated for lags of -2 to 9 months, although the correlation is not statistically significant at the 5-percent level. At stations 16618000 and 16620000 in northwestern Maui, average base flow during January to March and 3-month average SOI are both positively and negatively correlated for lags of -2 to 9 months, and the correlation is not statistically significant at the 5-percent level. In general, average base flow during the winter months of January to March tends to be low during or following El Niño (negative-SOI) periods and high during or following La Niña (positive-SOI) periods that occur during positive PDO phases. Also during positive PDO phases, statistically significant positive correlation between average base flow for January to March and 3-month average SOI was detected for at least one lag from -73 to -74 months at six of the 16 long-term-trend stations, for at least one lag from 36 to 70 months at six stations, and for at least one lag from 95 to 100 months at 10 stations (16068000 on Kauai; 16200000, 16211600, and 16229000 on Oahu; 16400000 on Molokai; all four stations on Maui; and 16720000 on Hawaii).

During positive PDO phases, statistically significant negative correlation between average base flow for January to March and 3-month average SOI was detected for at least one lag from -31 to -50 months at 14 of the 16 long-term-trend stations, and for at least three lags from -31 to -50 months at 10 of the 16 stations (16019000 on Kauai; 16200000, 16211600, 16226000, and 16303003 on Oahu; all four stations on Maui; and 16717000 on Hawaii) (fig. 27). Also during positive PDO phases, statistically significant negative correlation between average base flow for January to March and 3-month average SOI was detected for at least one lag from 11 to 33 months at six stations.

Base Flow, Negative PDO Phase.— During negative PDO phases, statistically significant positive correlation between average base flow for January to March and 3-month average SOI was detected for at least one lag from -120 to 120 months at 14 of the 16 long-term-trend stations, statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 12 of the 16 stations, and no statistically significant correlation was detected for lags from -120 to 120 months at one of the 16 stations (16508000 on Maui) (fig. 28).

During negative PDO phases at stations on Kauai (16019000, 16068000, and 16108000), Oahu (16200000, 16226000, and 16229000), Molokai (16400000), and Hawaii (16717000), significant positive correlation was detected between average base flow for the winter months of January to March and the 3-month average SOI for at least one lag between -4 to 8 months. Also during negative PDO phases, statistically significant positive correlation between average base flow for January to March and 3-month average SOI was detected for at least one lag from -58 to -117 months at nine of the 16 long-term-trend stations (16019000 and 16097500 on Kauai; 16211600, 16226000, 16229000, and 16303003 on Oahu; 16400000 on Molokai; and 16587000 and 16620000 on Maui), and for at least one lag from 73 to 103 months at nine stations (16068000, 16097500 and 16108000 on Kauai; 16211600, 16226000, 16229000, and 16303003 on Oahu; and 16717000 and 16720000 on Hawaii).

During negative PDO phases, statistically significant negative correlation between average base flow for January to March and 3-month average SOI was detected for at least one lag from -6 to -49 months at seven of the 16 long-term-trend stations, and for at least one lag from 13 to 39 months at six of the 16 stations (fig. 28). During negative PDO phases at stations on Kauai (16108000), Oahu (16226000 and 16229000), and Maui (16618000 and 16620000), significant negative correlation exists between average base flow for the winter months of January to March and the 3-month average SOI for at least one lag between 20 to 21 months.

April to June

Total Flow, Positive PDO Phase.—During positive PDO phases, statistically significant positive correlation (5-percent level of significance) between average total flow for April to June and 3-month average SOI was detected for at least one lag from -120 to 120 months at all 16 of the long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 15 stations (fig. 29).

During positive PDO phases, statistically significant positive correlation between average total flow for April to June and 3-month average SOI was detected for at least one lag from 1 to 14 months at nine of the 16 long-term-trend stations (16068000, 16097500, and 16108000 on Kauai; 16211600, 16226000, 16229000, and 16303003 on Oahu; 16508000 on Maui; and 16717000 on Hawaii), and for at least one lag from 75 to 84 months at six stations (fig. 29). For positive PDO

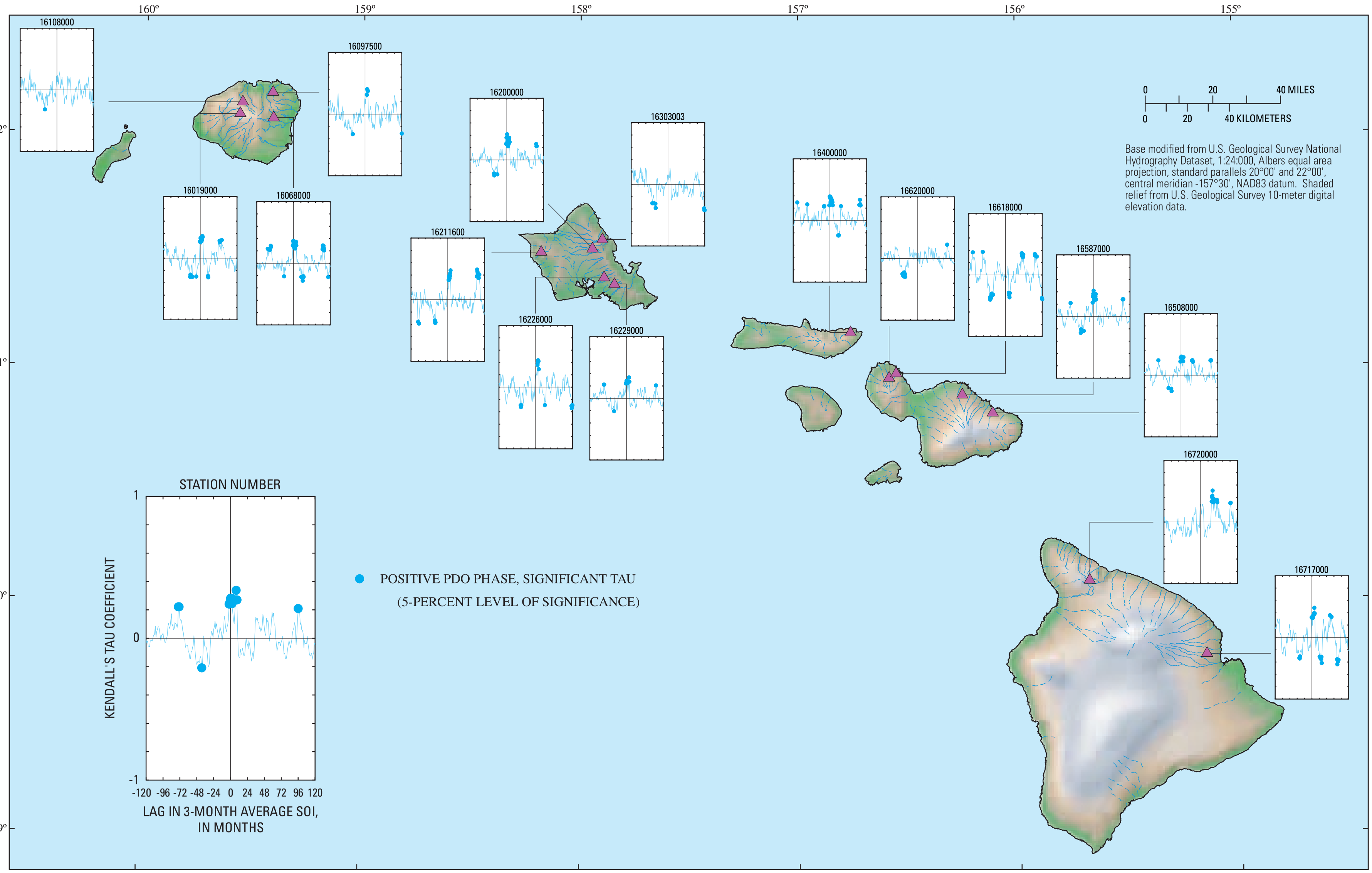

Figure 27. Relation between 3-month (January to March) average base flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

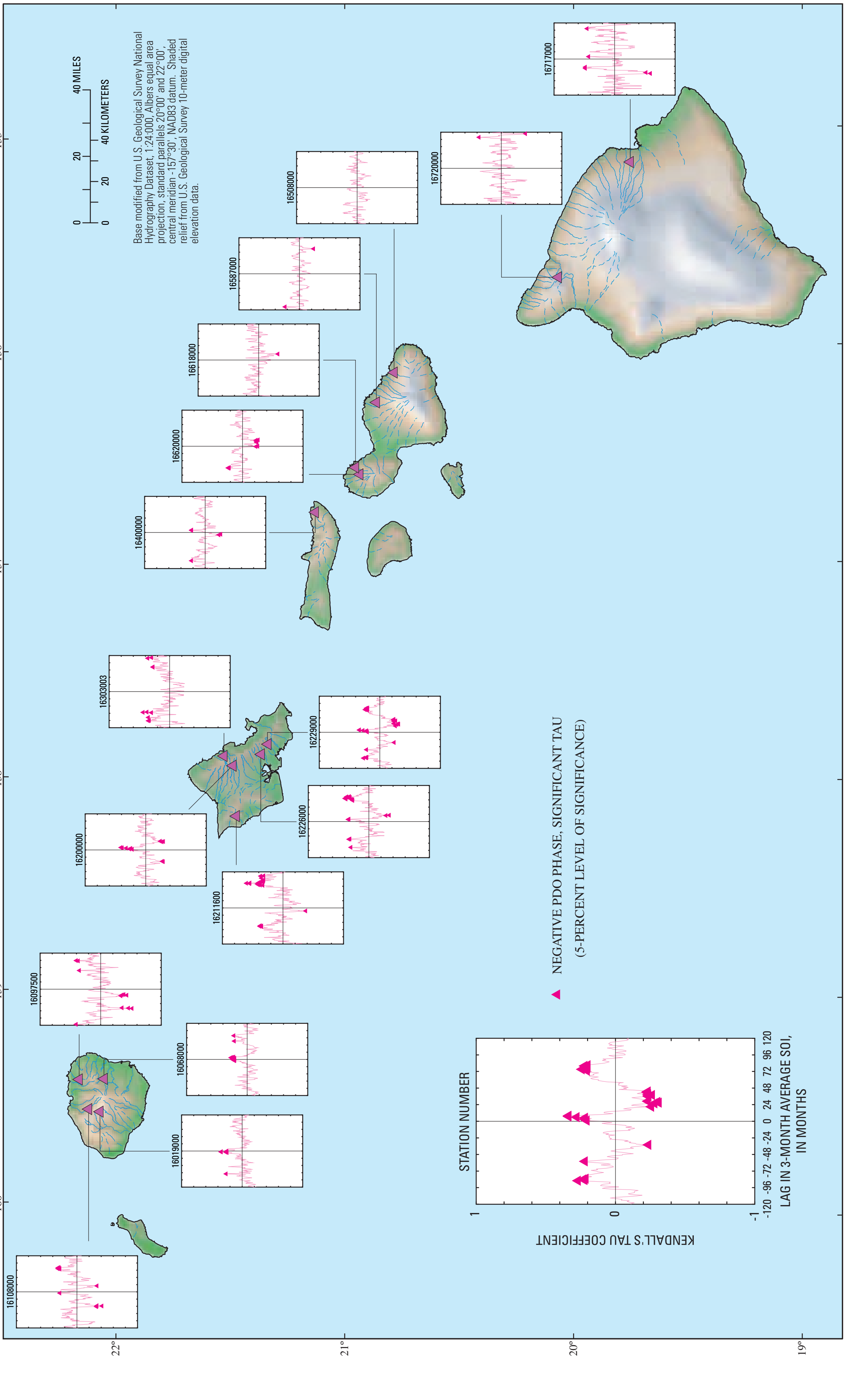

Figure 28. Relation between 3-month (January to March) average base flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

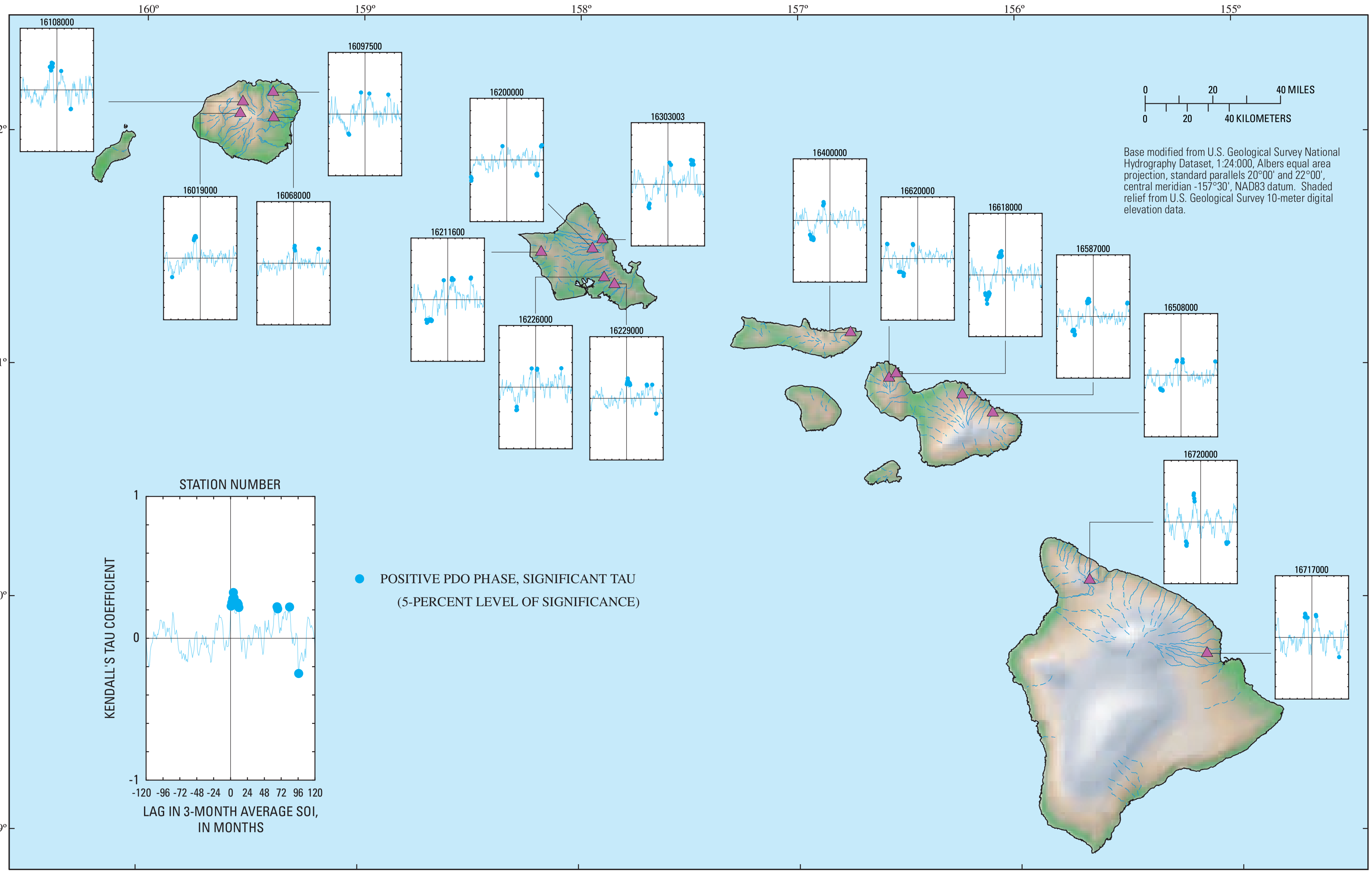

Figure 29. Relation between 3-month (April to June) average total flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

phases and lags from about 0 to 9 months, the percentage of stations with significant positive correlation between average total flow and the 3-month average SOI is higher during the months of January to March than during the months of April to June.

Also during positive PDO phases, statistically significant positive correlation between average total flow for April to June and 3-month average SOI was detected for at least one lag from -12 to -23 months at 13 of the 16 long-term-trend stations, and for at least two lags from -12 to -23 months at nine of the 16 stations (including stations 16019000 and 16108000 on Kauai, and all stations on Molokai, Maui, and Hawaii) (fig. 29). The positive correlation at negative lags indicates that average total flow during the months of April to June tends to be low 1 to 2 years prior to El Niño periods and high 1 to 2 years prior to La Niña periods that occur during positive PDO phases. However, statistically significant positive correlation between average total flow for April to June and 3-month average SOI also was detected for positive lags, which may be a manifestation of a quasi-cyclic relation between average total flow for April to June and 3-month average SOI.

During positive PDO phases, statistically significant negative correlation between average total flow for April to June and 3-month average SOI was detected for at least two lags from -45 to -70 months at 10 of the 16 long-term-trend stations (16097500 on Kauai; 16211600, 16226000, and 16303003 on Oahu; 16400000 on Molokai; all four stations on Maui; and 16720000 on Hawaii).

Total Flow, Negative PDO Phase.—During negative PDO phases, statistically significant positive correlation between average total flow for April to June and 3-month average SOI was detected for at least one lag from -120 to 120 months at 15 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 14 of the 16 stations (fig. 30).

During negative PDO phases, statistically significant positive correlation between average total flow for April to June and 3-month average SOI was detected for at least one lag from -49 to -87 months at five of the 16 long-term-trend stations, for at least one lag from 1 to 7 months at six stations, and for at least one lag from 80 to 114 months at 12 stations (16068000, 16097500, and 16108000 on Kauai; 16200000, 16211600, 16229000 on Oahu; 16400000 on Molokai; 16508000, 16587000, and 16620000 on Maui; 16717000 and 16720000 on Hawaii).

During negative PDO phases, statistically significant negative correlation between average total flow for April to June and 3-month average SOI was detected for at least one lag from -99 to -117 months at seven of the 16 long-term-trend stations, for at least one lag from -5 to -11 months at six stations, and for at least one lag from 18 to 23 months at eight stations.

Base Flow, Positive PDO Phase.—In general, during positive PDO phases the relation between base flow during April to June and 3-month average SOI (fig. 31) is similar to the relation for total flow. During positive PDO phases, statistically significant positive correlation between average base flow for April to June and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at all 16 of the long-term-trend stations, and statistically significant negative correlation was detected for at least one monthly lag from -120 to 120 months at 14 of the 16 long-term-trend stations.

During positive PDO phases, statistically significant positive correlation between average base flow for April to June and 3-month average SOI was detected for at least one lag from -12 to -24 months at 12 of the 16 long-term-trend stations (16019000, 16097500, and 16108000 on Kauai; 16200000 and 16226000 on Oahu; and all stations on Molokai, Maui, and Hawaii), and for at least one lag from 1 to 13 months at nine stations (16068000 and 16097500 on Kauai; all five stations on Oahu; and 16508000 and 16587000 on Maui) .

During positive PDO phases, statistically significant negative correlation between average base flow for April to June and 3-month average SOI was detected for at least one lag from -41 to -63 months at 11 of the 16 long-term-trend stations (16097500 on Kauai; 16200000, 16211600, 16226000, and 16303003 on Oahu; all stations on Molokai and Maui; and 16720000 on Hawaii) (fig. 31).

Base Flow, Negative PDO Phase.—During negative PDO phases, statistically significant positive correlation between average base flow for April to June and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at all 16 of the long-term-trend stations, and statistically significant negative correlation also was detected for at least one monthly lag from -120 to 120 months at all 16 of the long-term-trend stations (fig. 32).

During negative PDO phases, statistically significant positive correlation between average base flow for April to June and 3-month average SOI was detected for at least one lag from -2 to 9 months at seven of the 16 long-term-trend stations, and for at least one lag from 80 to 110 months at 10 stations (16019000, 16068000, and 16097500 on Kauai; 16200000, 16211600, 16229000, and 16303003 on Oahu; 16400000 on Molokai; 16587000 on Maui; and 16717000 on Hawaii).

During negative PDO phases, statistically significant negative correlation between average base flow for April to June and 3-month average SOI was detected for at least one lag from -108 to -118 months at 11 of the 16 long-term-trend stations (16019000, 16068000, and 16108000 on Kauai; 16200000 and 16226000 on Oahu; 16400000 on Molokai; all four stations on Maui; and 16720000 on Hawaii), for at least one lag from -5 to -37 months at six stations, and for at least one lag from 12 to 48 months at 10 stations (16019000, 16097500, and 16108000 on Kauai; 16200000, 16211600, and 16229000 on Oahu; 16587000, 16618000, and 16620000 on Maui; and 16717000 on Hawaii (fig. 32).

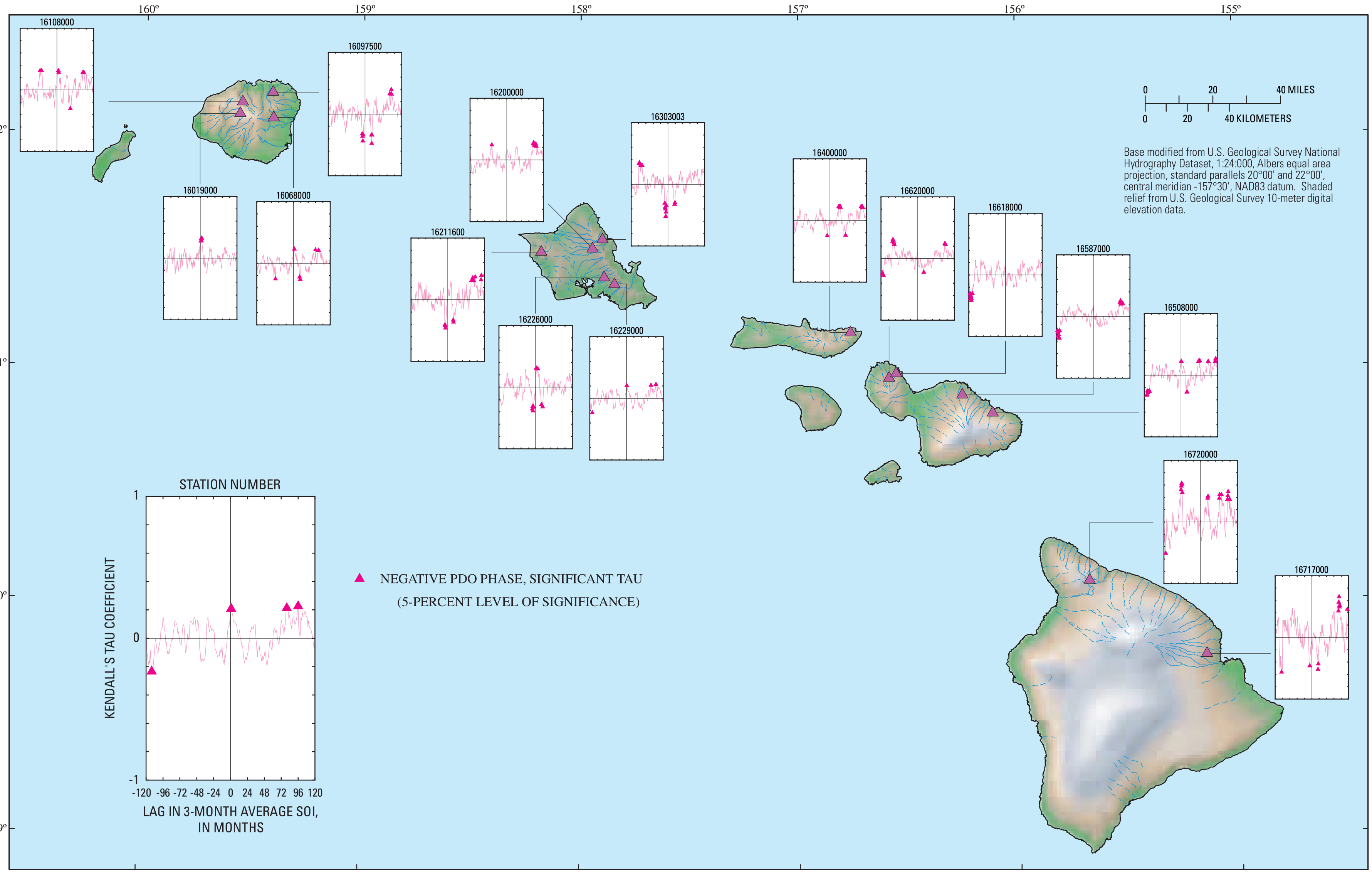

Figure 30. Relation between 3-month (April to June) average total flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

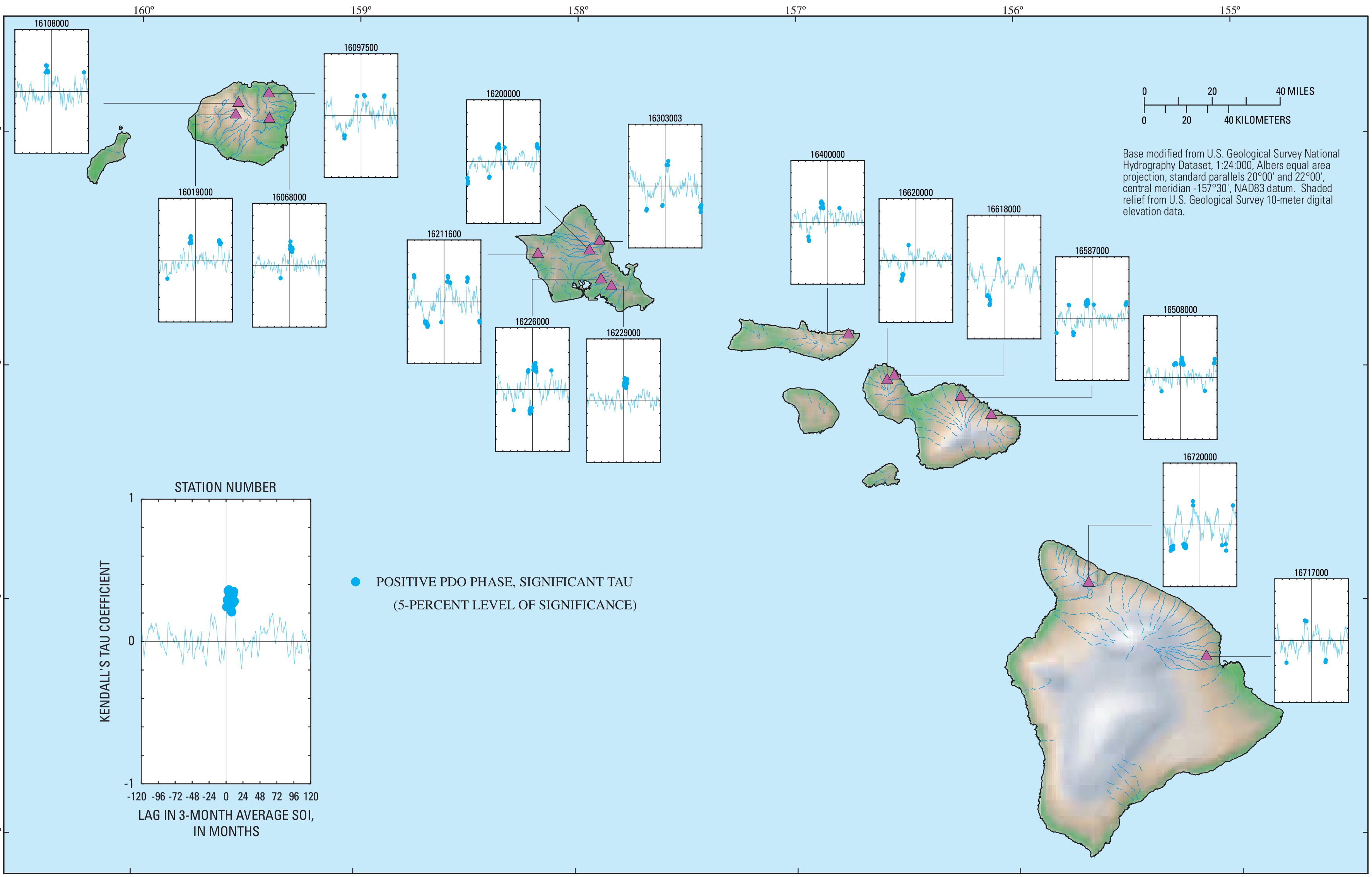

Figure 31. Relation between 3-month (April to June) average base flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

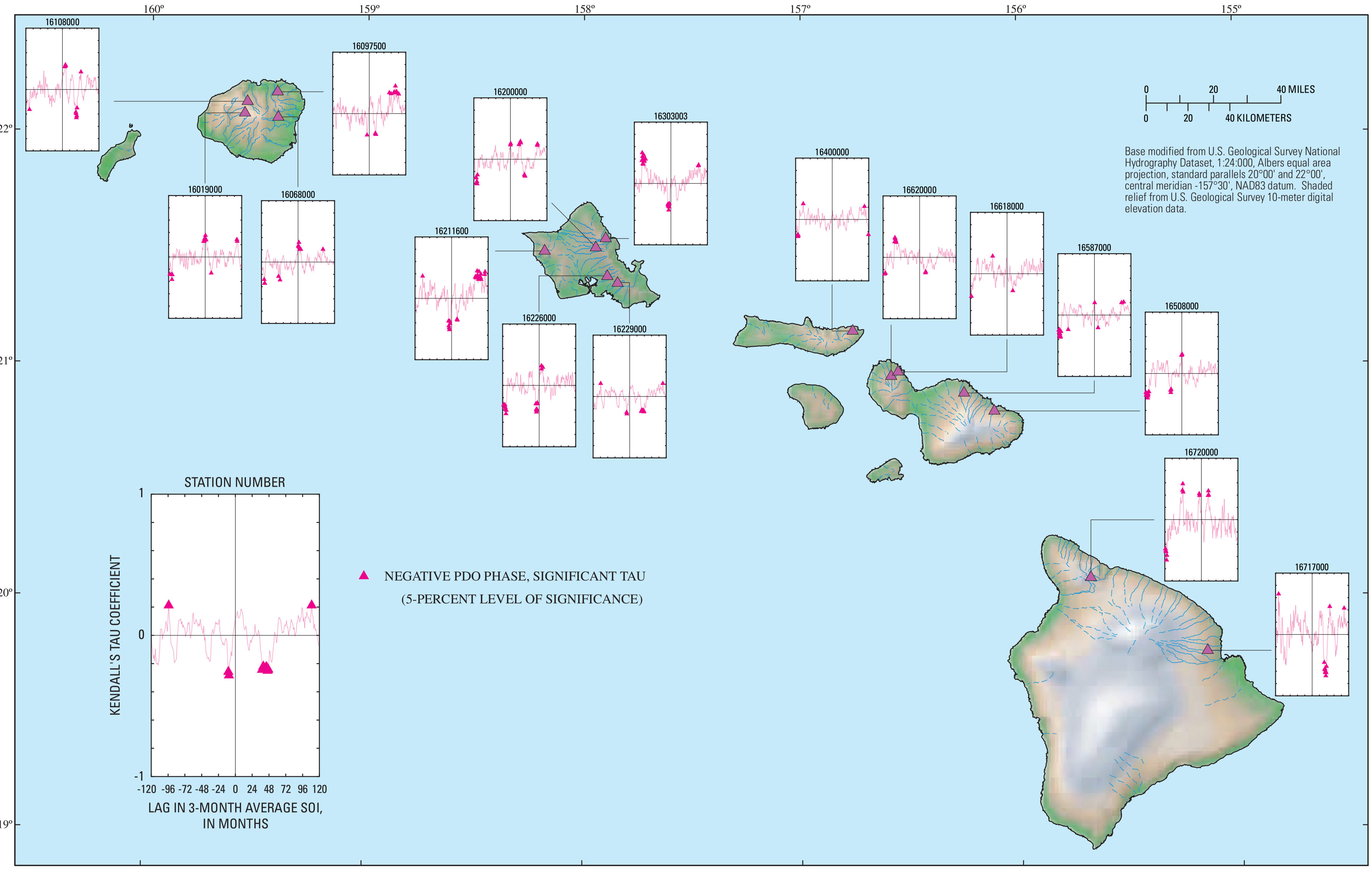

Figure 32. Relation between 3-month (April to June) average base flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

July to September

Total Flow, Positive PDO Phase.—During positive PDO phases, statistically significant positive correlation (5-percent level of significance) between average total flow for July to September and 3-month average SOI was detected for at least one lag from -120 to 120 months at 15 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 12 stations (fig. 33). During positive PDO phases, statistically significant negative correlation was not detected for lags from -120 to 120 months at any of the four long-term-trend stations on Kauai.

During positive PDO phases, statistically significant positive correlation between average total flow for July to September and 3-month average SOI was detected for at least one lag from -70 to -90 months at 13 of the 16 long-term-trend stations (16019000, 16068000, and 16108000 on Kauai; 16200000, 16226000, and 16229000 on Oahu; and all stations on Molokai, Maui, and Hawaii), and for at least one lag from 20 to 52 months at five stations (fig. 33).

During positive PDO phases, statistically significant negative correlation between average total flow for July to September and 3-month average SOI was detected for at least two lags from -8 to 11 months at 11 of the 16 long-term-trend stations, and for at least two lags from -8 to 0 months at 10 of the 16 stations (fig. 33). Statistically significant negative correlation between average total flow for July to September and 3-month average SOI was not detected for lags from -8 to 11 months at the four stations on Kauai (16019000, 16068000, 16097500, and 16108000) and the one station in western Oahu (16211600).

At most of the long-term-trend stations throughout the State, statistically significant positive correlation between average total flow for July to September and 3-month average SOI for lags of -70 to -90 months indicates that average total flow for July to September tends to be low 6 to 8 years prior to El Niño (negative-SOI) periods and high 6 to 8 years prior to La Niña (positive-SOI) periods that occur during positive PDO phases. However, in the southeastern part of the State, statistically significant negative correlation between average total flow for July to September and 3-month average SOI for lags of -8 to 0 months indicates that average total flow during the summer months of July to September also tends to be high within the 8 months prior to El Niño periods and low within the 8 months prior to La Niña periods that occur during positive PDO phases.

Total Flow, Negative PDO Phase.—During negative PDO phases, statistically significant positive correlation (5-percent level of significance) between average total flow for July to September and 3-month average SOI was detected for at least one lag from -120 to 120 months at 15 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 13 stations (fig. 34).

During negative PDO phases, statistically significant positive correlation between average total flow for July to September and 3-month average SOI was detected for at least one lag from -90 to -119 months at seven of the 16 long-term-trend stations, for at least one lag from -44 to -78 months at 12 stations (160109000, 16097500, and 16108000 on Kauai; 16200000, 16226000, 16229000, and 16303003 on Oahu; all four stations on Maui; and 16717000 on Hawaii), and for at least one lag from 85 to 117 months at 10 stations (16019000, 16097500, and 16108000 on Kauai; 16211600, 16229000, and 16303003 on Oahu; and all four stations on Maui) (fig. 34).

During negative PDO phases, statistically significant negative correlation between average total flow for July to September and 3-month average SOI was detected for at least one lag from -6 to 12 months at seven of the 16 long-term-trend stations (fig. 34).

Base Flow, Positive PDO Phase.—During positive PDO phases, statistically significant positive correlation between average base flow for July to September and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at 15 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one monthly lag from -120 to 120 months at 12 of the 16 long-term-trend stations (fig. 35).

During positive PDO phases, statistically significant positive correlation between average base flow for July to September and 3-month average SOI was detected for at least one lag from -70 to -95 months at 10 of the 16 long-term-trend stations (16019000 and 16068000 on Kauai; 16211600 and 16229000 on Oahu; 16400000 on Molokai; 16508000, 16587000, and 16618000 on Maui; and both stations on Hawaii), for at least one lag from -12 to -34 months at nine stations (16108000 on Kauai; 16200000, 16226000, and 16229000 on Oahu; 16400000 on Molokai; 16508000, 16587000, and 16620000 on Maui; and 16720000 on Hawaii), and for at least one lag from 3 to 52 months at seven stations (fig. 35).

During positive PDO phases, statistically significant negative correlation between average base flow for July to September and 3-month average SOI was detected for at least one lag from -48 to -59 months at 10 of the 16 long-term-trend stations (16097500 on Kauai; 16211600, 16229000, and 16303003 on Oahu; 16400000 on Molokai; 16587000, 16618000, and 16620000 on Maui; and both stations on Hawaii), and for at least one lag from -7 months to 1 month at six stations (fig. 35).

Base Flow, Negative PDO Phase.—During negative PDO phases, statistically significant positive correlation between average base flow for July to September and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at 14 of the 16 long-term-trend stations, statistically significant negative correlation was detected for at least one monthly lag from -120 to 120 months at 15 of the 16 long-term-trend stations, and no statistically significant correlation was detected for lags from -120 to 120 months at one station (16400000 on Molokai) (fig. 36).

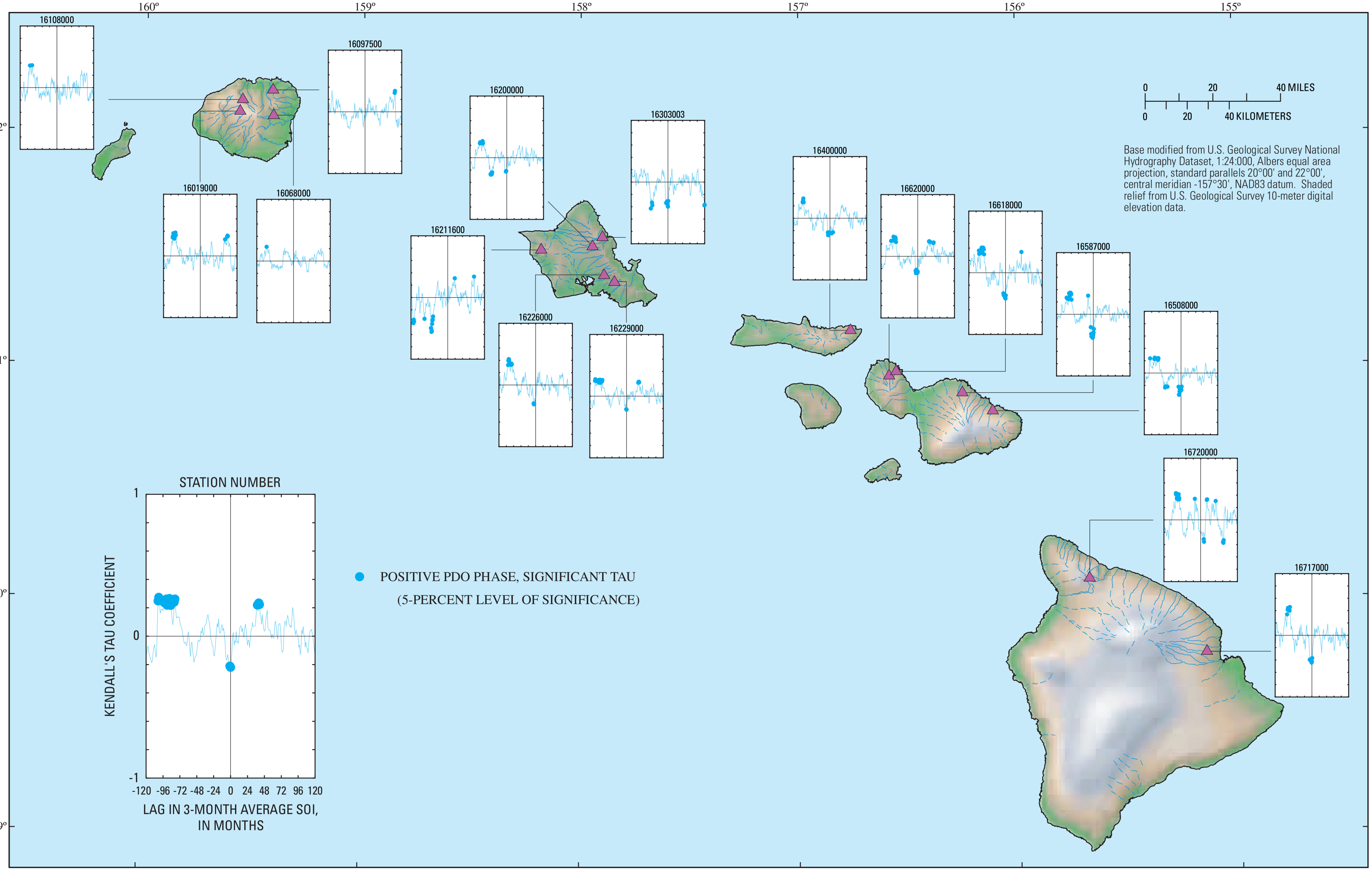

Figure 33. Relation between 3-month (July to September) average total flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

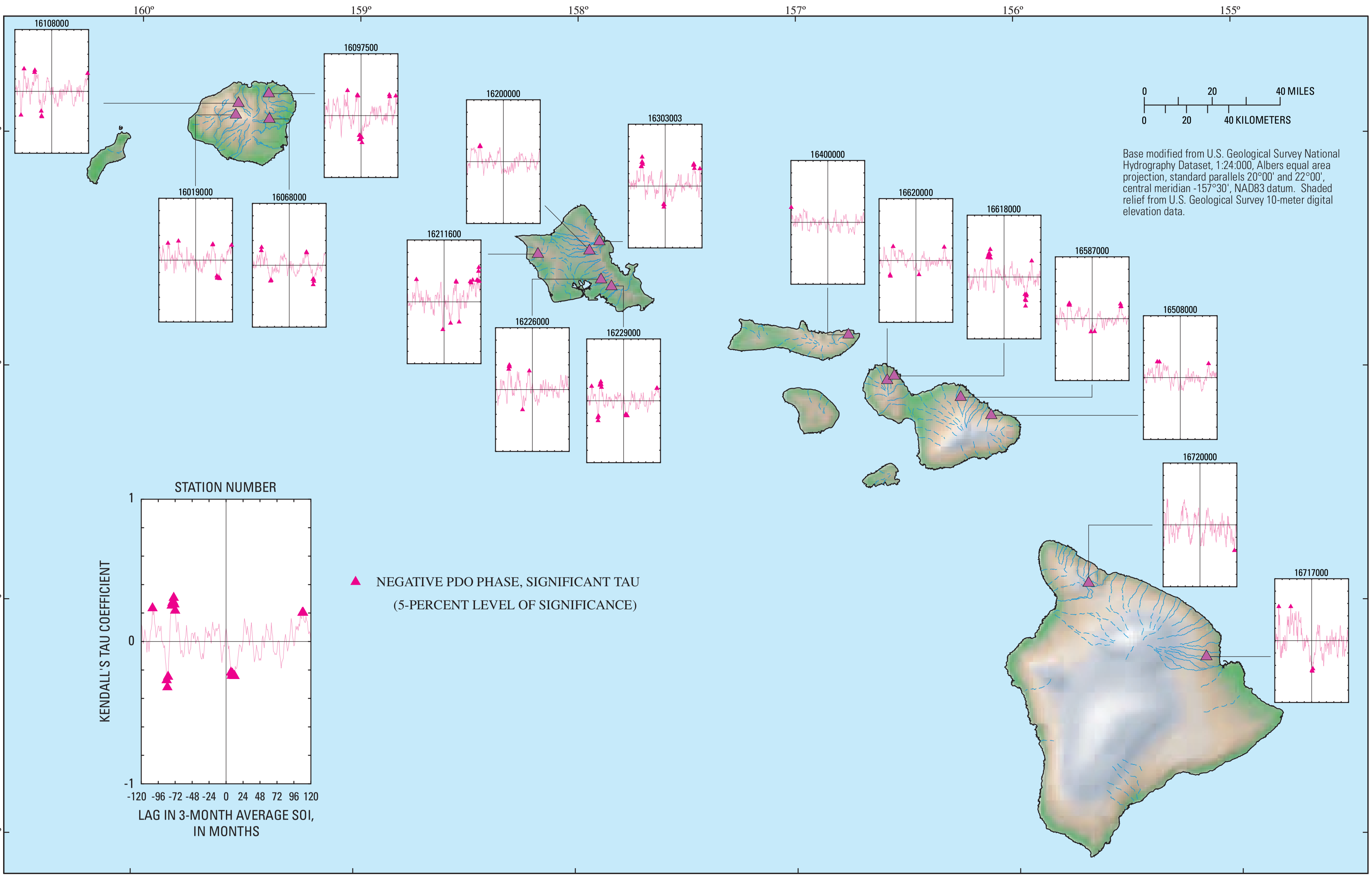

Figure 34. Relation between 3-month (July to September) average total flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

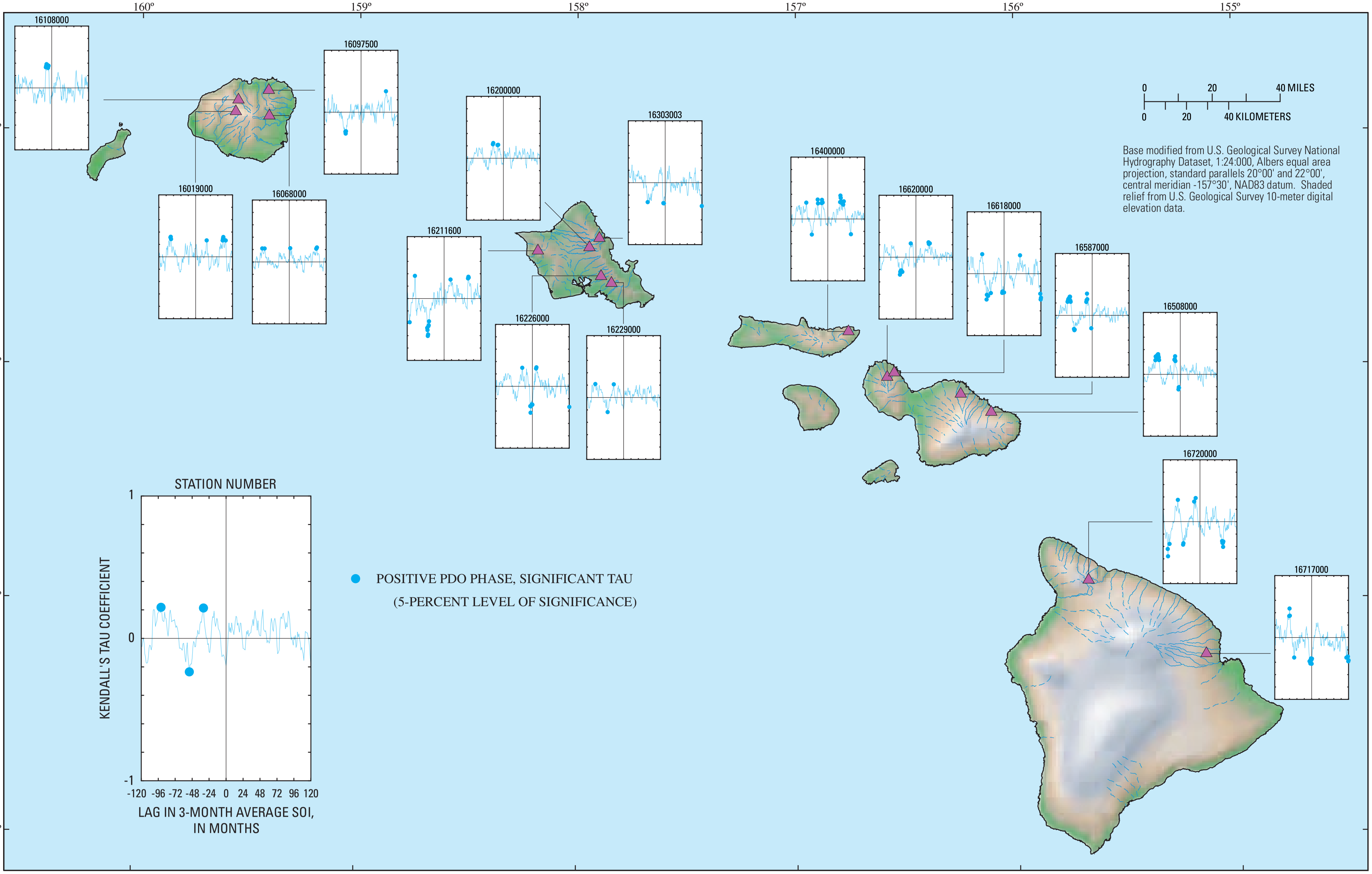

Figure 35. Relation between 3-month (July to September) average base flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

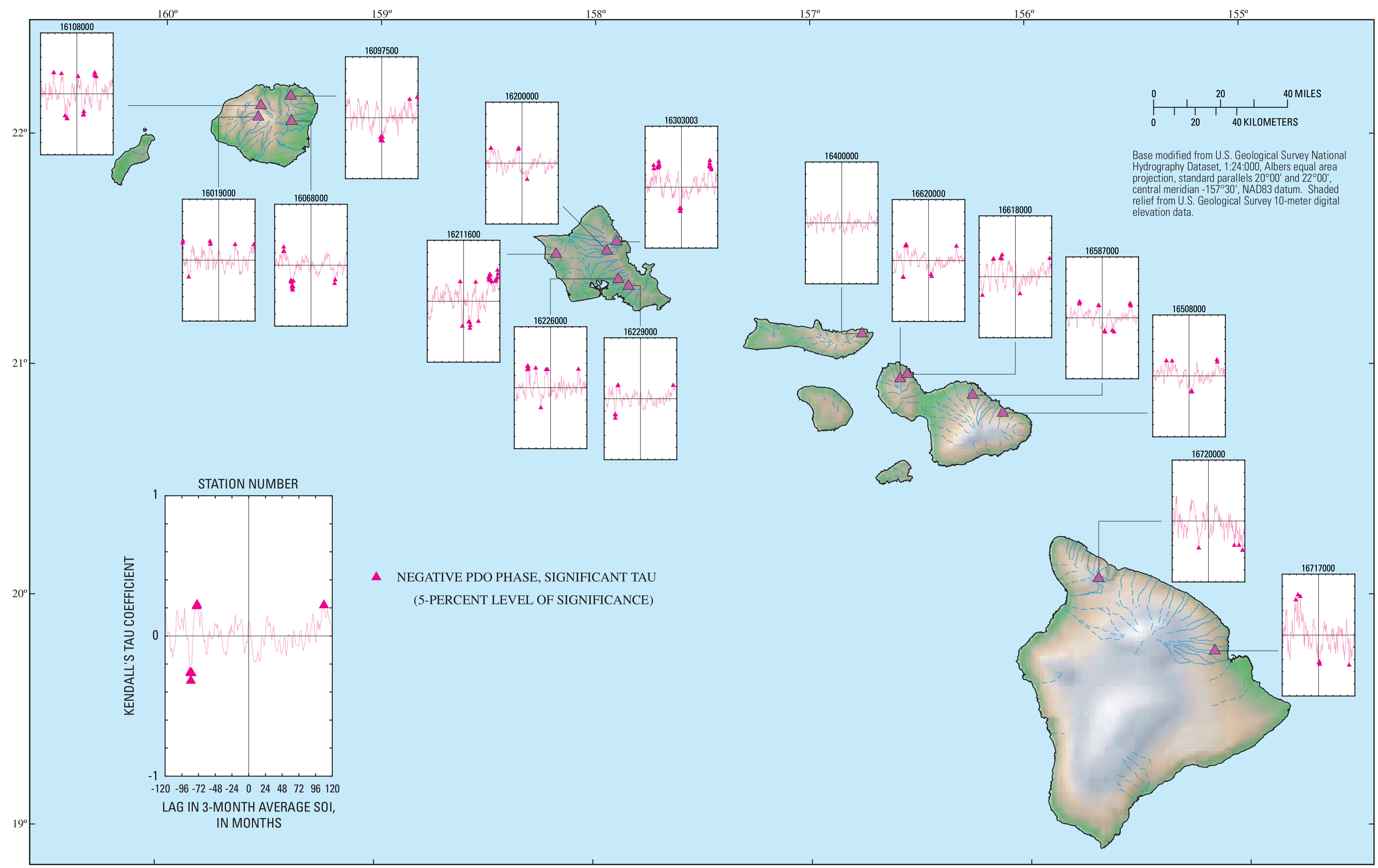

Figure 36. Relation between 3-month (July to September) average base flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

During negative PDO phases, statistically significant positive correlation between average base flow for July to September and 3-month average SOI was detected for at least one lag from -72 to -79 months at nine of the 16 long-term-trend stations (16108000 on Kauai; 16226000, 16229000, and 16303003 on Oahu; all four stations on Maui; and 16717000 on Hawaii), for at least one lag from -44 to -60 months at five stations, for at least one lag from -10 to -29 months at five stations, and for at least one lag from 92 to 117 months at 10 stations (16019000 and 16097500 on Kauai; 16211600, 16226000, 16229000, and 16303003 on Oahu; and all four stations on Maui) (fig. 36).

During negative PDO phases, statistically significant negative correlation between average base flow for July to September and 3-month average SOI was detected for at least one lag from -6 to 23 months at 10 of the 16 long-term-trend stations (16097500 and 16108000 on Kauai; 16200000, 16211600, and 16303003 on Oahu; all four stations on Maui; and 16717000 on Hawaii) (fig. 36).

October to December

Total Flow, Positive PDO Phase.—During positive PDO phases, statistically significant positive correlation (5-percent level of significance) between average total flow for October to December and 3-month average SOI was detected for at least one lag from -120 to 120 months at 14 of the 16 long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at all 16 stations (fig. 37).

During positive PDO phases, statistically significant positive correlation between average total flow for October to December and 3-month average SOI was detected for at least one lag from -91 to -110 months at eight of the 16 long-term-trend stations, and for at least one lag from -69 to -75 months at six stations (fig. 37).

During positive PDO phases, statistically significant negative correlation between average total flow for October to December and 3-month average SOI was detected for at least one lag from -34 to -57 months at 10 of the 16 long-term-trend stations (16200000, 16211600, and 16229000 on Oahu, and all stations on Molokai, Maui, and Hawaii), for at least one lag from 61 to 79 months at nine stations (16019000 and 16068000 on Kauai; 16200000, 16211600, 16226000, and 16229000 on Oahu; 16400000 on Molokai; and 16508000 and 16618000 on Maui), and for at least one lag from 115 to 119 months at eight stations (all four stations on Kauai; 16226000 and 16303003 on Oahu; 16400000 on Molokai; and 16618000 on Maui) (fig. 37).

Total Flow, Negative PDO Phase.—During negative PDO phases, statistically significant positive correlation (5-percent level of significance) between average total flow for October to December and 3-month average SOI was detected for at least one lag from -120 to 120 months at all 16 of the long-term-trend stations, and statistically significant negative correlation was detected for at least one lag from -120 to 120 months at 13 of the 16 stations (fig. 38).

During negative PDO phases, statistically significant positive correlation between average total flow for October to December and 3-month average SOI was detected for at least one lag from -61 to -119 months at 14 of the 16 long-term-trend stations (all stations except those on Hawaii), and for at least one lag from 30 to 47 months at six stations (fig. 38).

During negative PDO phases, statistically significant negative correlation between average total flow for October to December and 3-month average SOI was detected for at least one lag from -6 to 28 months at 11 of the 16 long-term-trend stations (16019000, 16068000, and 16097500 on Kauai; 16200000, 16229000, and 16303003 on Oahu; 16400000 on Molokai; and all four stations on Maui), and for at least one lag from 0 to 24 months at nine of the 16 stations (16019000, 16068000, and 16097500 on Kauai; 16200000 and 16229000 on Oahu; 16400000 on Molokai; and 16508000, 16587000, and 16620000 on Maui) (fig. 38).

Base Flow, Positive PDO Phase.—During positive PDO phases, statistically significant positive correlation between average base flow for October to December and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at 13 of the 16 long-term-trend stations, statistically significant negative correlation also was detected for at least one monthly lag from -120 to 120 months at 13 of the 16 long-term-trend stations, and no statistically significant correlation was detected for monthly lags from -120 to 120 months at one station (16108000 on Kauai) (fig. 39).

During positive PDO phases, statistically significant positive correlation between average base flow for October to December and 3-month average SOI was detected for at least one lag from -67 to -74 months at eight of the 16 long-term-trend stations (16019000 on Kauai; 16200000 on Oahu; 16400000 on Molokai; all four stations on Maui; and 16717000 on Hawaii), and for at least one lag from -10 to -30 months at six stations (fig. 39).

During positive PDO phases, statistically significant negative correlation between average base flow for October to December and 3-month average SOI was detected for at least one lag from -45 to -56 months at nine of the 16 long-term-trend stations (16068000 and 16097500 on Kauai; 16200000, 16211600, 16229000, and 16303003 on Oahu; 16618000 and 16620000 on Maui; and 16717000 on Hawaii), and for at least one lag from -3 to 21 months at seven stations (fig. 39).

Base Flow, Negative PDO Phase.—During negative PDO phases, statistically significant positive correlation between average base flow for October to December and 3-month average SOI was detected for at least one monthly lag from -120 to 120 months at all 16 of the long-term-trend stations, and statistically significant negative correlation was detected for at least one monthly lag from -120 to 120 months at 14 of the 16 long-term-trend stations (fig. 40).

During negative PDO phases, statistically significant positive correlation between average base flow for October to December and 3-month average SOI was detected for at least

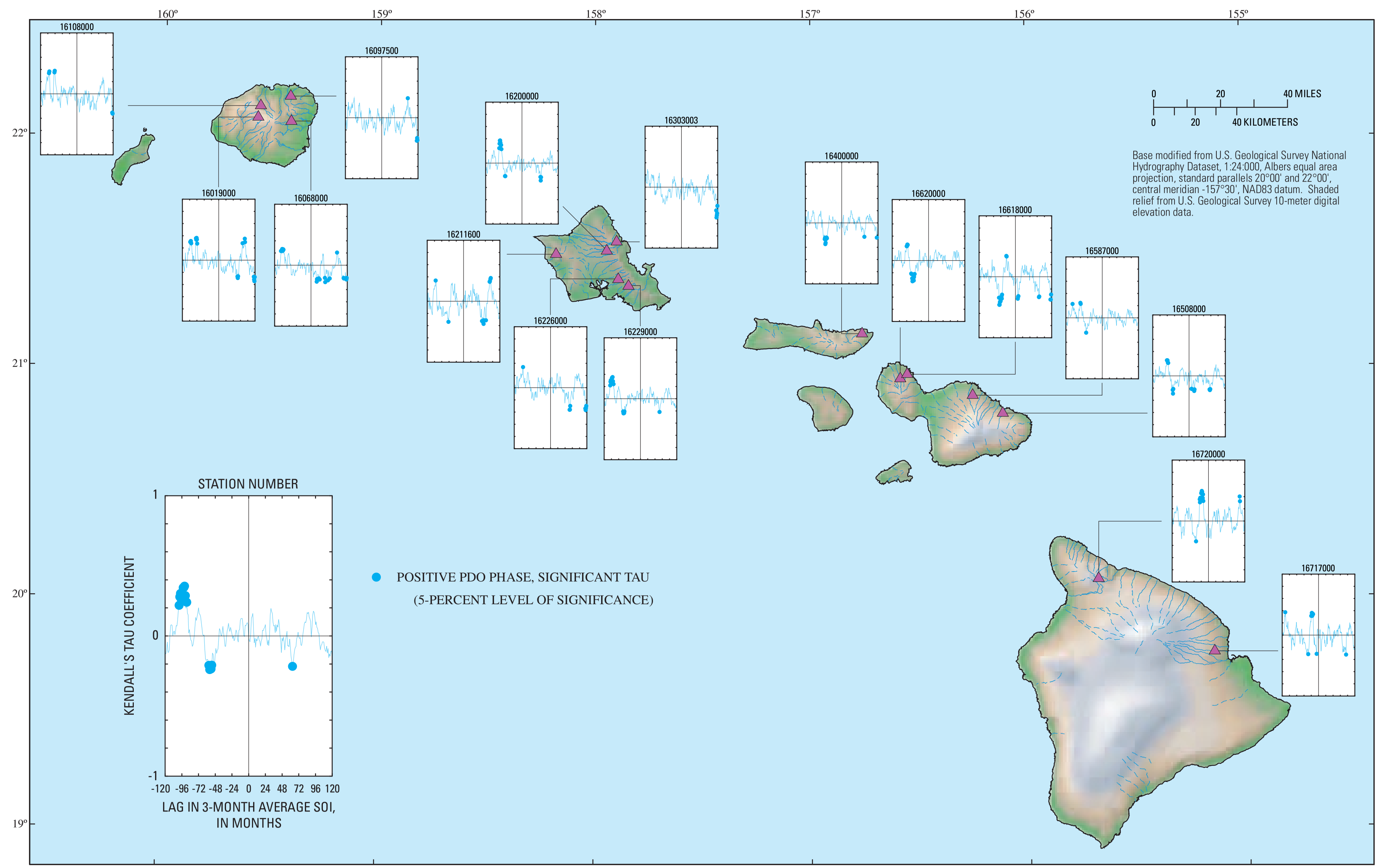

Figure 37. Relation between 3-month (October to December) average total flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

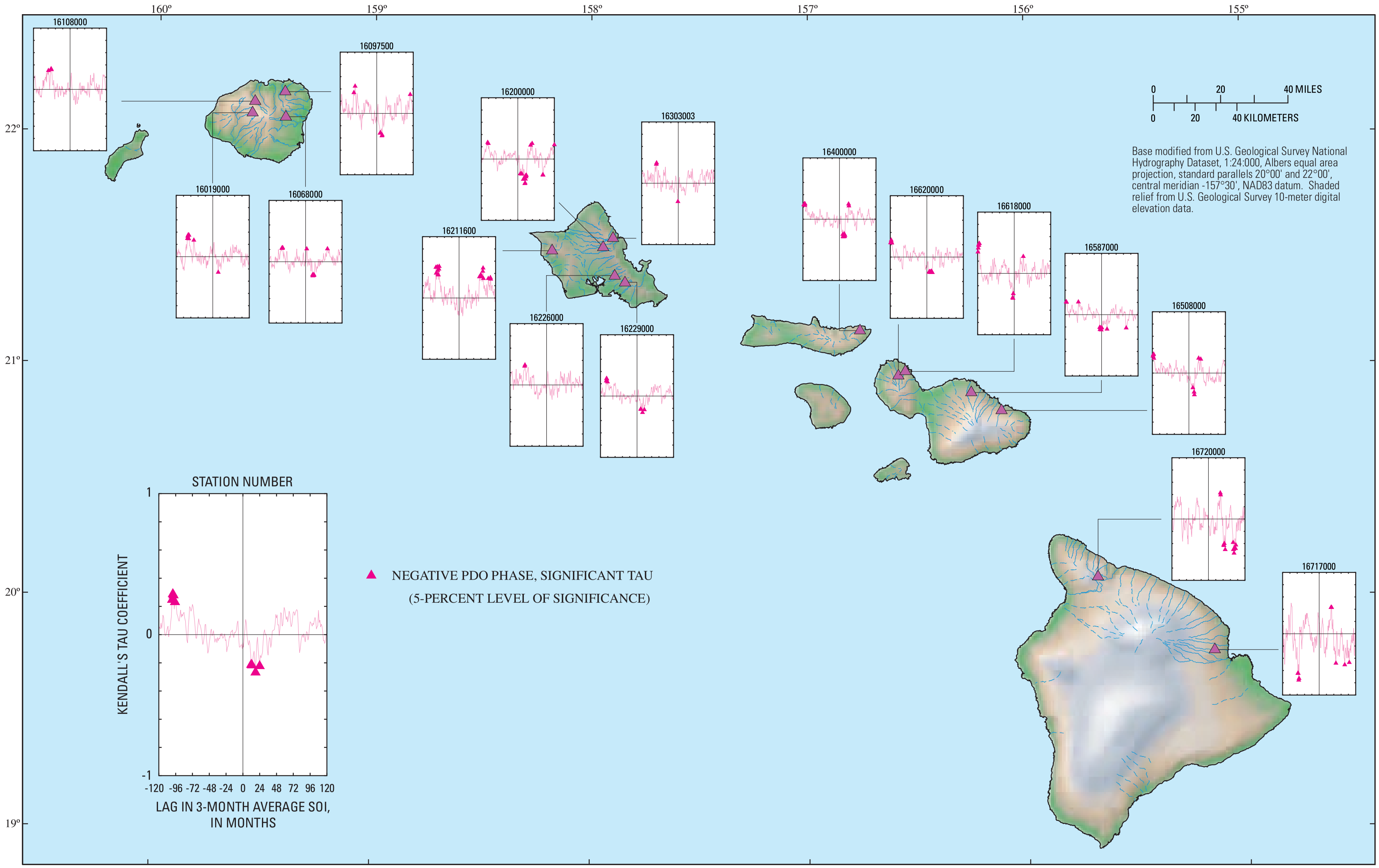

Figure 38. Relation between 3-month (October to December) average total flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

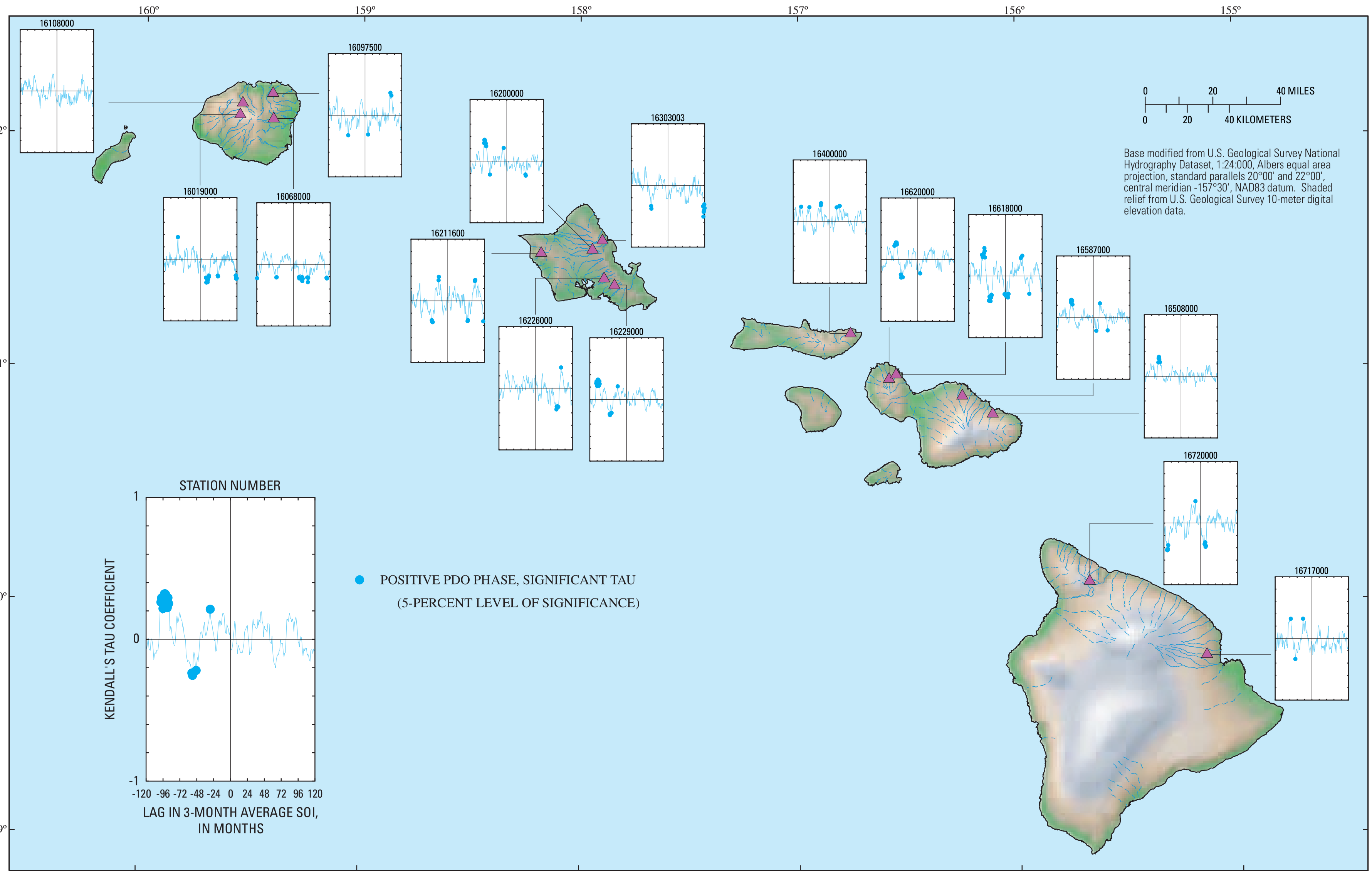

Figure 39. Relation between 3-month (October to December) average base flow during positive Pacific Decadal Oscillation (PDO) phase (water years 1925–1946 and 1977–1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

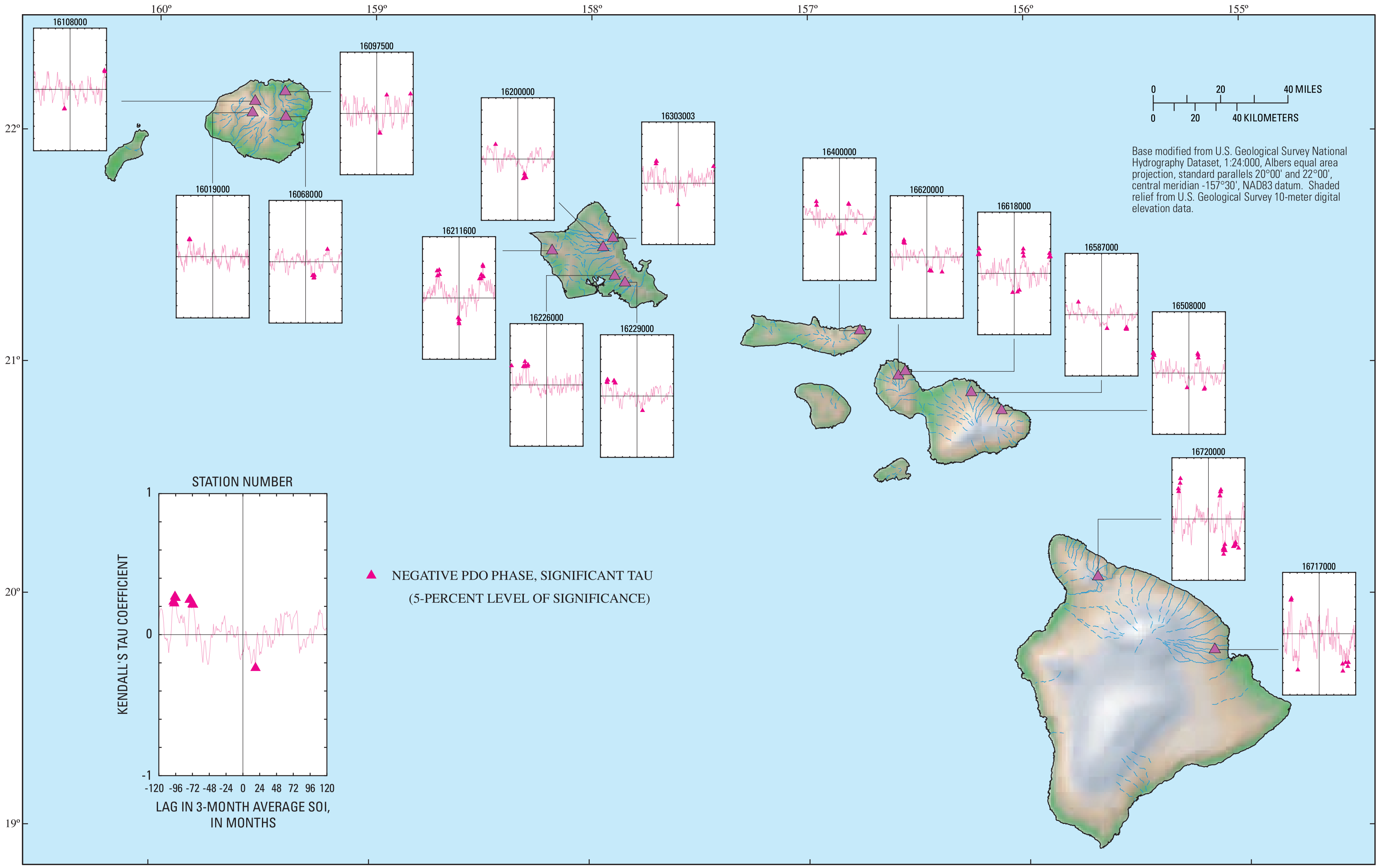

Figure 40. Relation between 3-month (October to December) average base flow during negative Pacific Decadal Oscillation (PDO) phase (water years before 1925, 1947–1976, and after 1998) and 3-month average Southern Oscillation Index (SOI) with lags of -120 to +120 months, State of Hawaii. Positive lags indicate 3-month average SOI precedes 3-month average flow, and negative lags indicate 3-month average flow precedes 3-month average SOI. Only complete water years (prior to and including water year 2002) of data used.

one lag from -61 to -99 months at 11 of the 16 long-term-trend stations (16019000 on Kauai; all five stations on Oahu; 16400000 on Molokai; 16587000 and 16620000 on Maui; and both stations on Hawaii), and for at least one lag from 29 to 41 months at five stations (fig. 40).

During negative PDO phases, statistically significant negative correlation between average base flow for October to December and 3-month average SOI was detected for at least one lag from -6 to 28 months at 11 of the 16 long-term-trend stations (16068000 and 16097500 on Kauai; 16200000, 16211600, 16229000, and 16303003 on Oahu; 16400000 on Molokai; and all four stations on Maui), and for at least one lag from 0 to 24 months at nine of the 16 stations (16068000 and 16097500 on Kauai; 16200000, 16211600, and 16229000 on Oahu; 16400000 on Molokai; and 16587000, 16618000, and 16620000 on Maui) (fig. 40).

Summary of Patterns in Relations Among Flow, Southern Oscillation Index, and Pacific Decadal Oscillation

One of the salient relations among streamflow, SOI, and PDO is the nearly statewide positive correlation, during periods of positive PDO phase, between winter (January to March) streamflow and SOI during the previous 0 to 9 months. This positive correlation indicates that average total flow (and to a lesser extent average base flow) during the winter months of January to March tends to be low following El Niño periods and high following La Niña periods, particularly during positive PDO phases. In Hawaii, drier than normal winter months commonly follow ENSO events (Chu, 1995). At the long-term-trend stations, the positive correlation between winter (January to March) flow and SOI during the previous 0 to 9 months is more widespread for total flow than base flow, which indicates that ENSO may be more strongly related to processes controlling direct runoff than ground-water discharge during the winter months.

During positive PDO phases, statistically significant negative correlation between average total flow (and base flow) for January to March and 3-month average SOI during the subsequent 1 to 4 years was detected at most of the long-term-trend stations. At many of the long-term-trend stations, a pattern of positive correlation between flow and SOI for some monthly lags and negative correlation at other lags may indicate that the relation between flow and SOI during both positive and negative PDO phases is quasi-cyclic.

For the months of April to June, statistically significant positive correlation between average total flow and 3-month average SOI during the previous 1 to 14 months was detected at most of the long-term-trend stations during positive PDO phases. However, the percentage of stations with significant positive correlation between average total flow and the 3-month average SOI during the previous 1 to 14 months is higher for flow during the months of January to March than during the months of April to June. During positive PDO phases, statistically significant positive correlation between average total flow for April to June and 3-month average SOI during the subsequent 12 to 23 months was detected at 13 of the 16 long-term-trend stations (including three of four stations on Kauai, three of five stations on Oahu, and all stations on Molokai, Maui, and Hawaii). This positive correlation between average total flow for April to June and 3-month average SOI during the subsequent 12 to 23 months indicates that average total flow during the months of April to June tends to be low 1 to 2 years prior to El Niño periods and high 1 to 2 years prior to La Niña periods that occur during positive PDO phases. Because the relation between streamflow and SOI may be quasi-cyclic, it is difficult to discern whether low streamflow during April to June is caused by ENSO or whether factors that cause low streamflow during April to June help to initiate ENSO. During positive PDO phases, the relations between average base flow during April to June and SOI are similar to those for average total flow.

For the summer months of July to September, statistically significant positive correlation between average total flow and 3-month average SOI during the subsequent 70 to 90 months was detected at most of the long-term-trend stations, particularly during positive PDO phases. This positive correlation indicates that average total flow for July to September tends to be low 6 to 8 years prior to El Niño periods and high 6 to 8 years prior to La Niña periods that occur during positive PDO phases. However, in the southeastern part of the State, statistically significant negative correlation between average total flow for July to September and 3-month average SOI during the subsequent 0 to 8 months indicates that average total flow during the summer months of July to September also tends to be high within the 8 months prior to El Niño periods and low within the 8 months prior to La Niña periods that occur during positive PDO phases. At the long-term-trend stations during positive PDO phases, the positive correlation between summer (July to September) flow and SOI during the subsequent 70 to 90 months and the negative correlation between summer flow and SOI during the subsequent 0 to 8 months is more widespread for total flow than base flow.

During the months of October to December, patterns in the relations between flow and SOI generally are less well-defined than for other months. For the months of October to December, patterns in the relations between flow and SOI for the long-term-trend stations are more prevalent during negative PDO phases than positive PDO phases. For the months of October to December, statistically significant negative correlation between flow (average total flow and base flow) and 3-month average SOI during the previous 0 to 24 months was detected at most of the long-term-trend stations during negative PDO phases. Statistically significant negative correlation between flow for October to December and 3-month average SOI during the previous 0 to 24 months indicates that flow during the months of October to December tends to be high 0 to 2 years following El Niño periods and low 0 to 2 years following La Niña periods that occur during negative PDO phases.

Analysis of the relations among streamflow, SOI, and PDO indicates that short-term variability in streamflow corresponds with ENSO and partly with the PDO. All available data from each of the long-term-trend stream-gaging stations were considered in the analysis, although no attempt was made to determine the effect of record length on the relations among flow, SOI, and PDO. For this study, positive and negative phases of the PDO were mainly based on periods defined by Mantua and others (1997), and no attempt was made to evaluate how the absolute magnitude of the PDO index affects the relations among flow, SOI, and PDO.

In general, ENSO is less strongly related to base flow than total flow, indicating that it is the direct-runoff component of total flow that is more closely related to ENSO. The relations among ENSO and PDO and flow characteristics are not always spatially uniform, indicating the need to maintain a network of stream-gaging stations throughout the State to improve the understanding of how ENSO and PDO relate to the State's surface-water resources. Further study is needed to determine whether regional climate indicators successfully can be used to predict streamflow trends and variations throughout the State, which further underscores the need to maintain a network of long-term-trend stream-gaging stations in Hawaii.

Summary

Proper management of the surface-water resources in Hawaii requires an understanding of long-term trends and variations in streamflow. Both short-term climatic variability and long-term climate changes affect streamflow and pose challenges to water users, water suppliers, and resource managers in the State. Many of the droughts in Hawaii are related to El Niño events, which are associated with drier than normal winters in Hawaii (Giambelluca and others, 1991; Chu, 1995). Long-term climate change may reduce streamflow availability in Hawaii for extended periods.

The U.S. Geological Survey maintains a network of stream-gaging stations in Hawaii, and this network includes active long-term-trend stations (Fontaine, 1996) at which continuous records of streamflow are collected. Data from 16 of these long-term stations are useful for examining trends in streamflow.

The overall objective of this study was to obtain a better understanding of long-term trends and variations in streamflow on the Hawaiian Islands of Hawaii, Maui, Molokai, Oahu, and Kauai. This study included (1) an analysis of long-term trends in flows (both total flow and estimated base flow) at 16 of the long-term-trend stations identified by Fontaine (1996), (2) a description of patterns in trends within the State, and (3) discussion of possible regional factors (including rainfall, El Niño, and the Pacific Decadal Oscillation) that are related to the observed trends and variations.

Results of the long-term-trend analysis using the Mann-Kendall test indicate that (1) from 1913 to 2002, low flows generally decreased in streams for which data are available, and this trend is consistent with the long-term downward trend in rainfall over much of the State during that period; (2) from 1933 to 2002, overall trends in low-flow characteristics generally were downward, although statistically significant downward trends were not detected at some stations; (3) from 1953 to 2002 and from 1973 to 2002, the percentage of stations with statistically significant downward trends in low flows decreased relative to the longer periods (1913 to 2002 and 1933 to 2002); and (4) from 1973 to 2002, statistically significant upward trends in selected flow characteristics were detected at stations on Kauai, Oahu, and Hawaii.

Monthly mean base flows generally were above the long-term average from 1913 to the early 1940s and below average after the early 1940s to 2002, and this pattern is consistent with the measured downward trends in base flows from 1913 to 2002. Long-term downward trends in base flows of streams may indicate a reduction in ground-water storage and recharge. Because ground water provides about 99 percent of Hawaii's domestic drinking water, a reduction in ground-water storage and recharge has serious implications for drinking-water availability. In addition, reduction in stream base flows may reduce habitat availability for native stream fauna and water availability for irrigation purposes.

The percentage of statistically significant trends in rainfall and flow for the period 1973 to 2002 is much lower than for the period 1913 to 2002. Detection of patterns in trends over time scales of a few decades may be confounded by high spatial and temporal variability in both rainfall and flow characteristics in Hawaii.

One of the salient relations among streamflow, the Southern Oscillation Index (SOI), and the Pacific Decadal Oscillation (PDO) is the nearly statewide positive correlation, during periods of positive PDO phase, between winter (January to March) streamflow and SOI during the previous 0 to 9 months. This positive correlation indicates that streamflow during the winter months of January to March tends to be low following El Niño periods and high following La Niña periods, particularly during positive PDO phases. At the long-term-trend stations, the correspondence of ENSO with flow during the winter months is more widespread for total flow than base flow, which indicates that ENSO corresponds more closely with direct runoff than with ground-water discharge. At many of the long-term-trend stations, a pattern of positive correlation between flow and SOI for some monthly lags and negative correlation at other lags may indicate that the relation between flow and SOI during both positive and negative PDO phases is quasi-cyclic.

For the months of April to June, statistically significant positive correlation between average total flow and 3-month average SOI during the previous 1 to 14 months was detected at most of the long-term-trend stations during positive PDO phases. However, the percentage of stations with significant positive correlation between average total flow and the 3-month average SOI during the previous 1 to 14 months is higher for flow during the months of January to March than during the months of April to June.

In the southeastern part of the State during the summer months of July to September, statistically significant negative correlation between average total flow and 3-month average SOI during the subsequent 0 to 8 months indicates that average total flow during the summer months of July to September tends to be high within the 8 months prior to El Niño periods and low within the 8 months prior to La Niña periods that occur during positive PDO phases.

During the months of October to December, patterns in the relations between flow and SOI generally are less well defined than for other months. For the months of October to December, consistent relations between flow and SOI for the long-term-trend stations are more prevalent during negative PDO phases than positive PDO phases.

The correspondence of ENSO and PDO with flow characteristics is not always spatially consistent, indicating the need to maintain a network of stream-gaging stations throughout the State to improve the understanding of how ENSO and PDO are related to the State's surface-water resources.

Data from long-term stream-gaging stations in Hawaii indicate the presence of both long-term (decadal) trends and short-term (interannual) variability. The time scales over which these changes occur reflect the factors that control base flow and direct runoff. In general, significant changes in base flow occur at much longer time scales than changes in direct runoff because base flow is controlled by ground-water recharge and storage, whereas direct runoff is controlled by rainfall. Long-term downward trends in low flows of streams may indicate reductions in ground-water discharge to streams caused by long-term decreases in ground-water storage. Short-term variability in streamflow is related to the El Niño-Southern Oscillation phenomenon, and this relation may be partly modulated by the Pacific Decadal Oscillation. The El Niño-Southern Oscillation phenomenon occurs at a relatively short time scale (years not decades), and more closely corresponds with variations in direct runoff than variations in base flow.

Further study is needed to determine (1) whether the downward trends in base flows from 1913 to 2002 will continue or whether the observed pattern is part of a long-term cycle in which base flows may eventually return to levels measured during 1913 to the early 1940s, (2) the physical causes for the detected trends and variations in streamflow, and (3) whether regional climate indicators successfully can be used to predict streamflow trends and variations throughout the State. These needs for future study underscore the need to maintain a network of long-term-trend stream-gaging stations in Hawaii.

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Appendix A

Annual Flow Statistics at Long-Term Stream-Gaging Stations, Hawaii

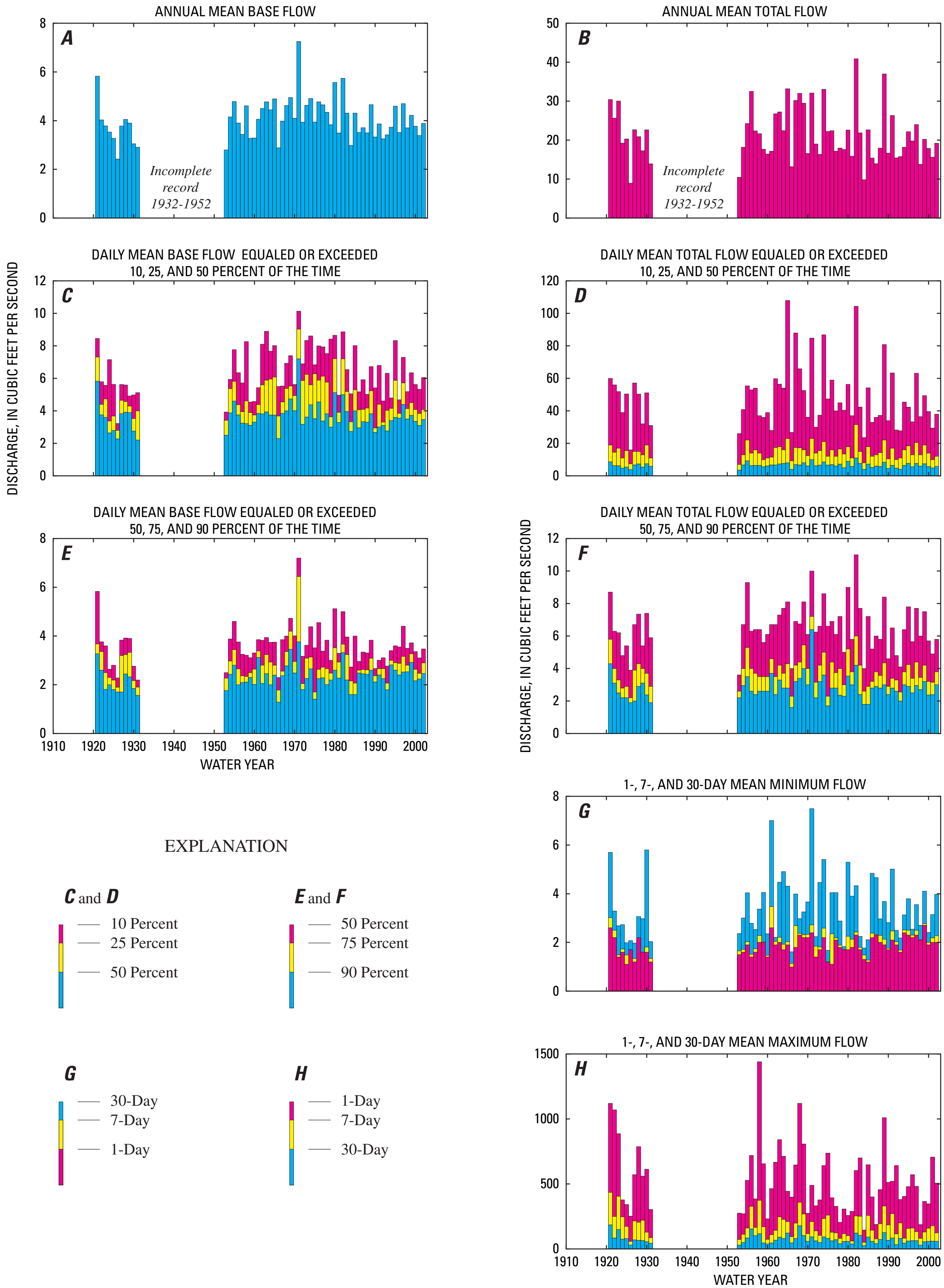

Figure A1. Annual time series for various flow statistics at stream-gaging station 16019000, Waialae Stream at altitude 3,820 feet near Waimea, Kauai, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

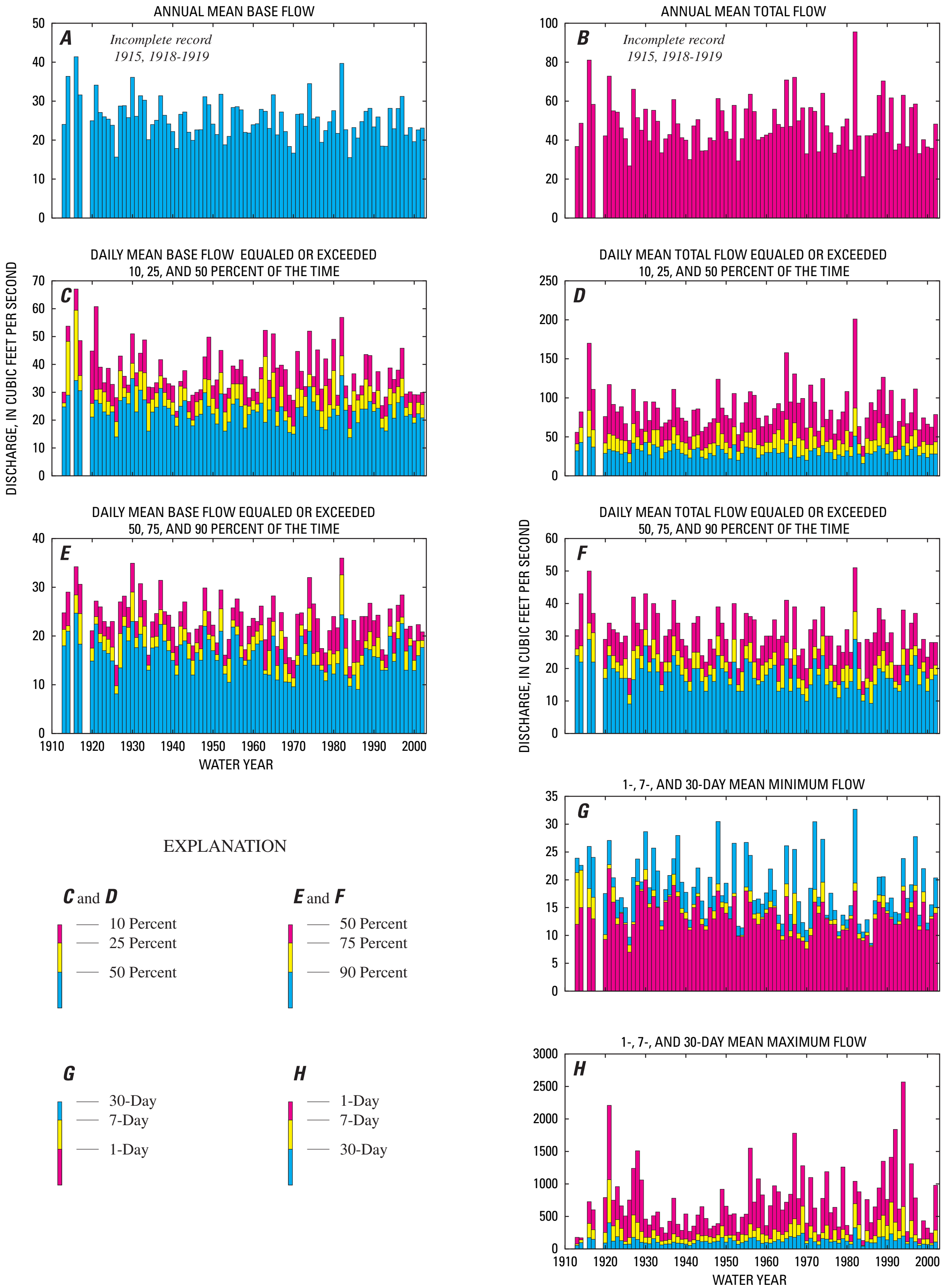

Figure A2. Annual time series for various flow statistics at stream-gaging station 16068000, East Branch of North Fork Wailua River near Lihue, Kauai, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

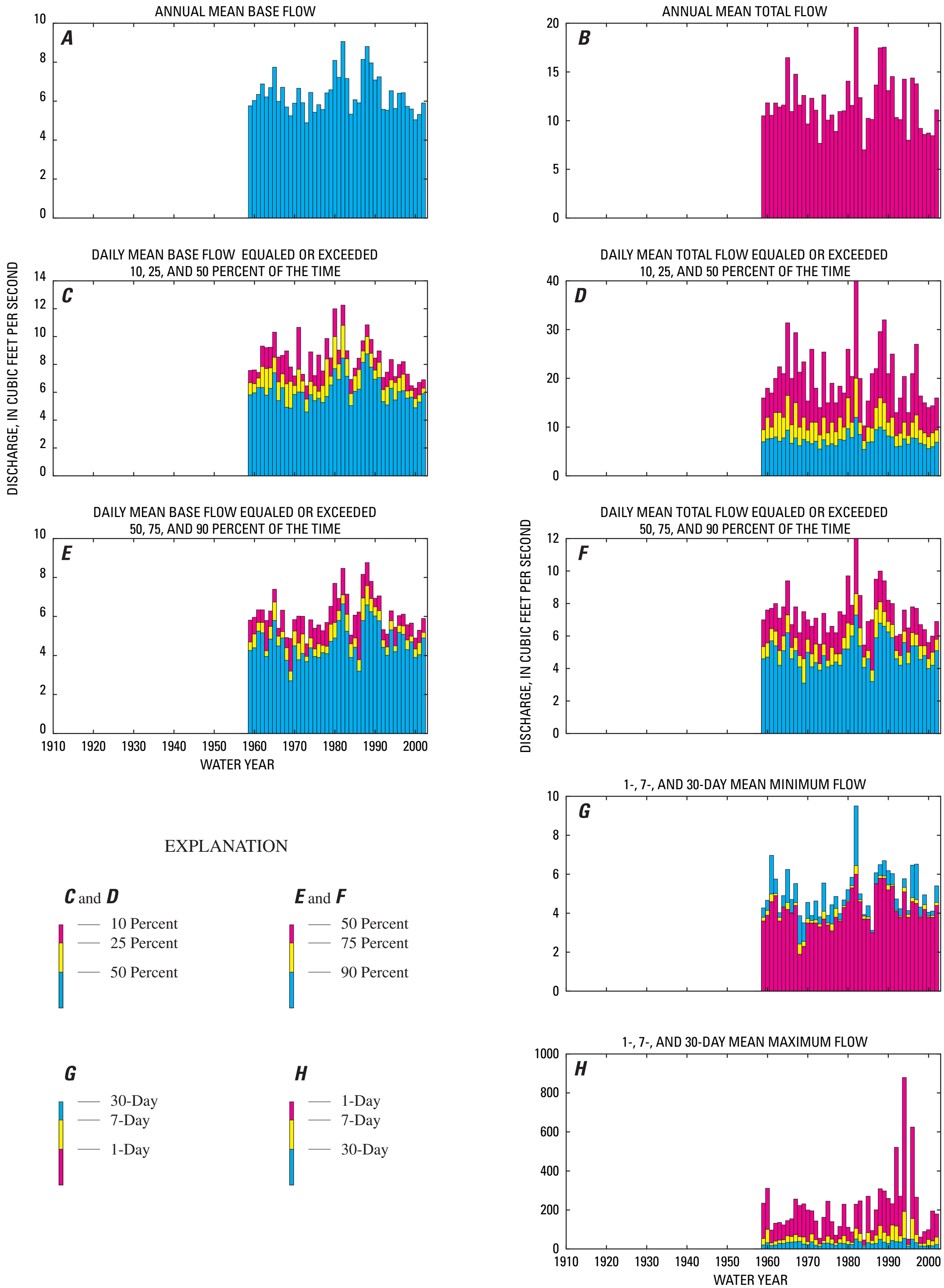

Figure A3. Annual time series for various flow statistics at stream-gaging station 16097500, Halaulani Stream at altitude 400 feet near Kilauea, Kauai, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

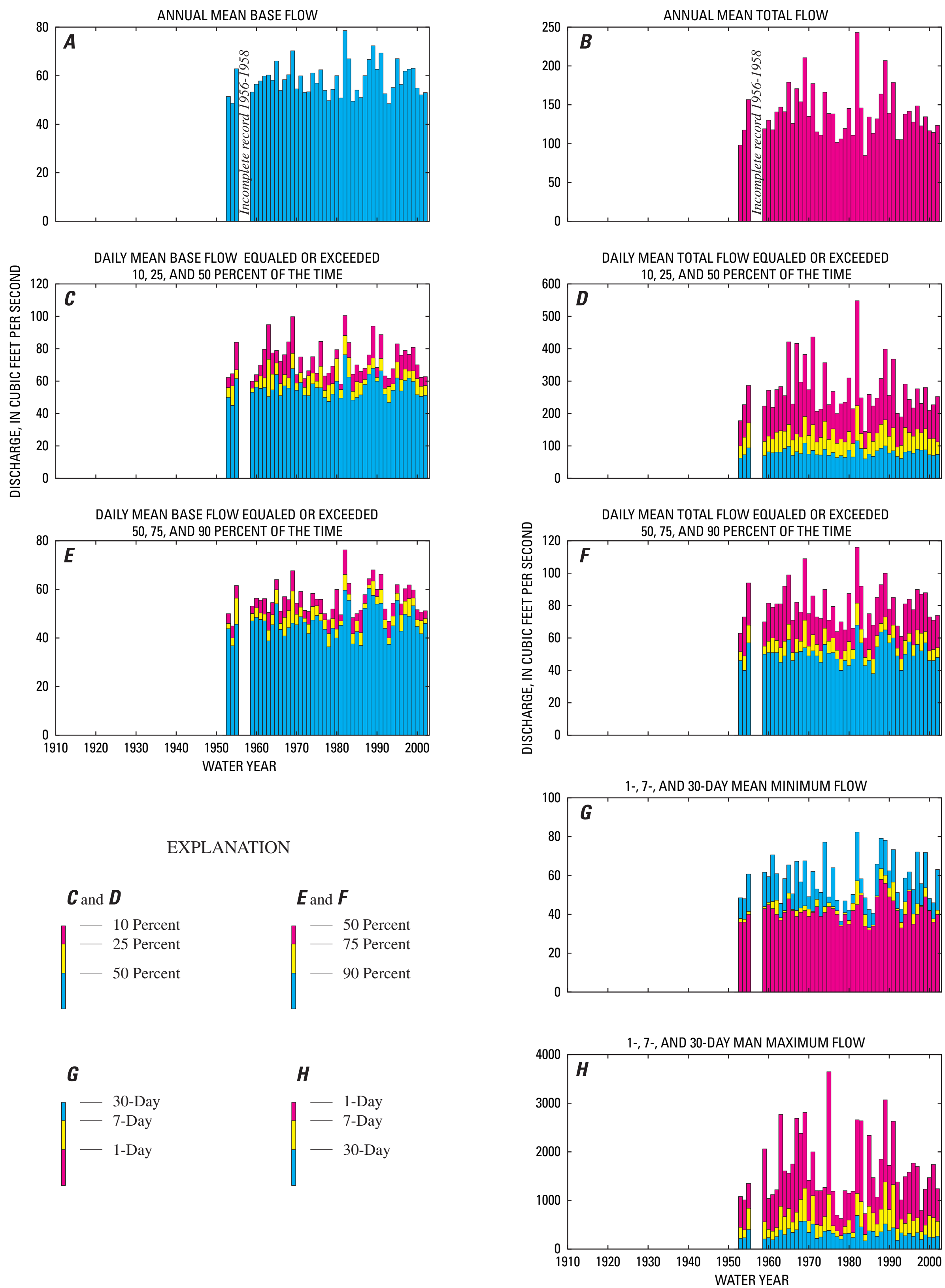

Figure A4. Annual time series for various flow statistics at stream-gaging station 16108000, Wainiha River near Hanalei, Kauai, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

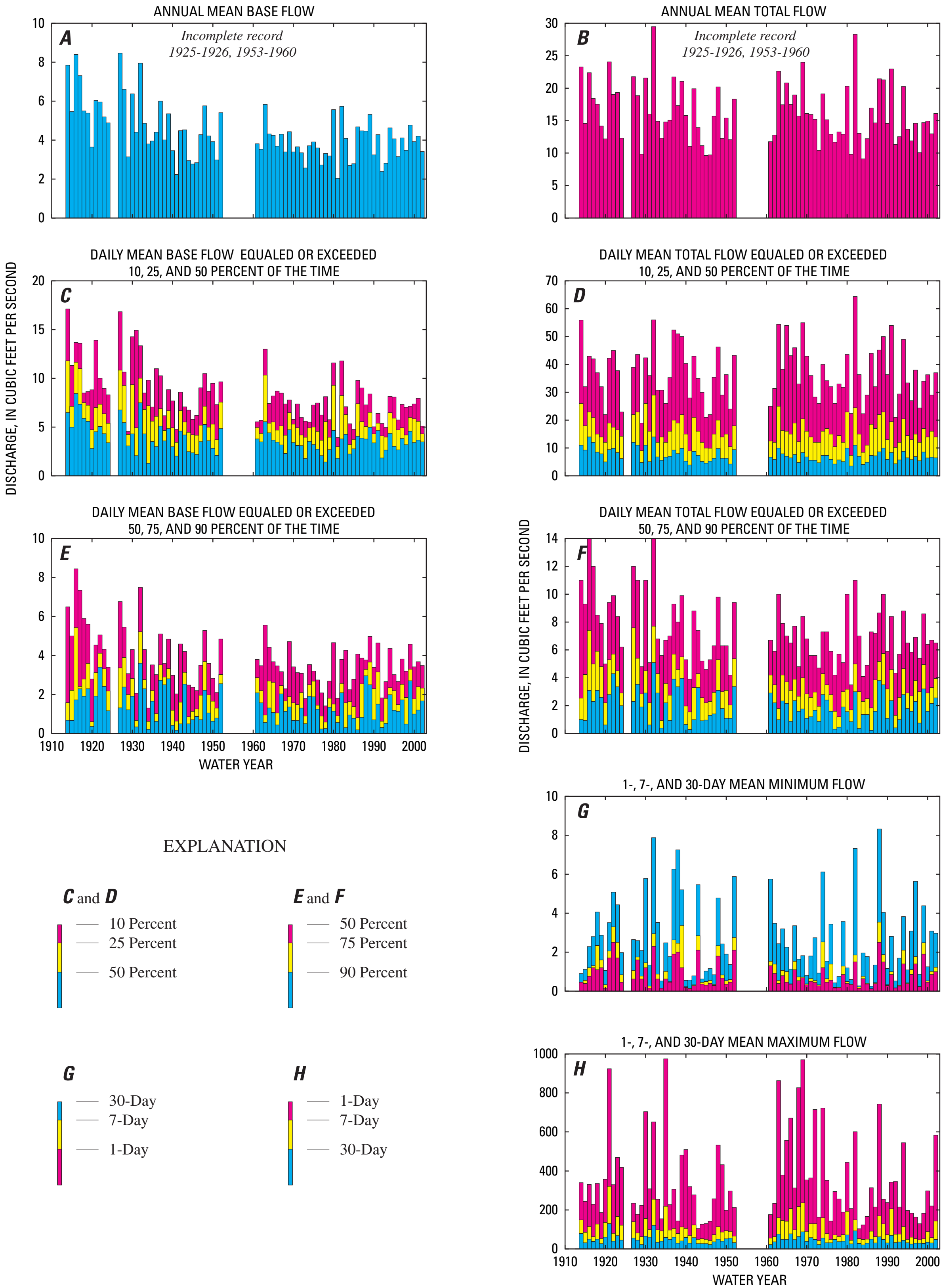

Figure A5. Annual time series for various flow statistics at stream-gaging station 16200000, North Fork Kaukonahua Stream above Right Branch near Wahiawa, Oahu, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

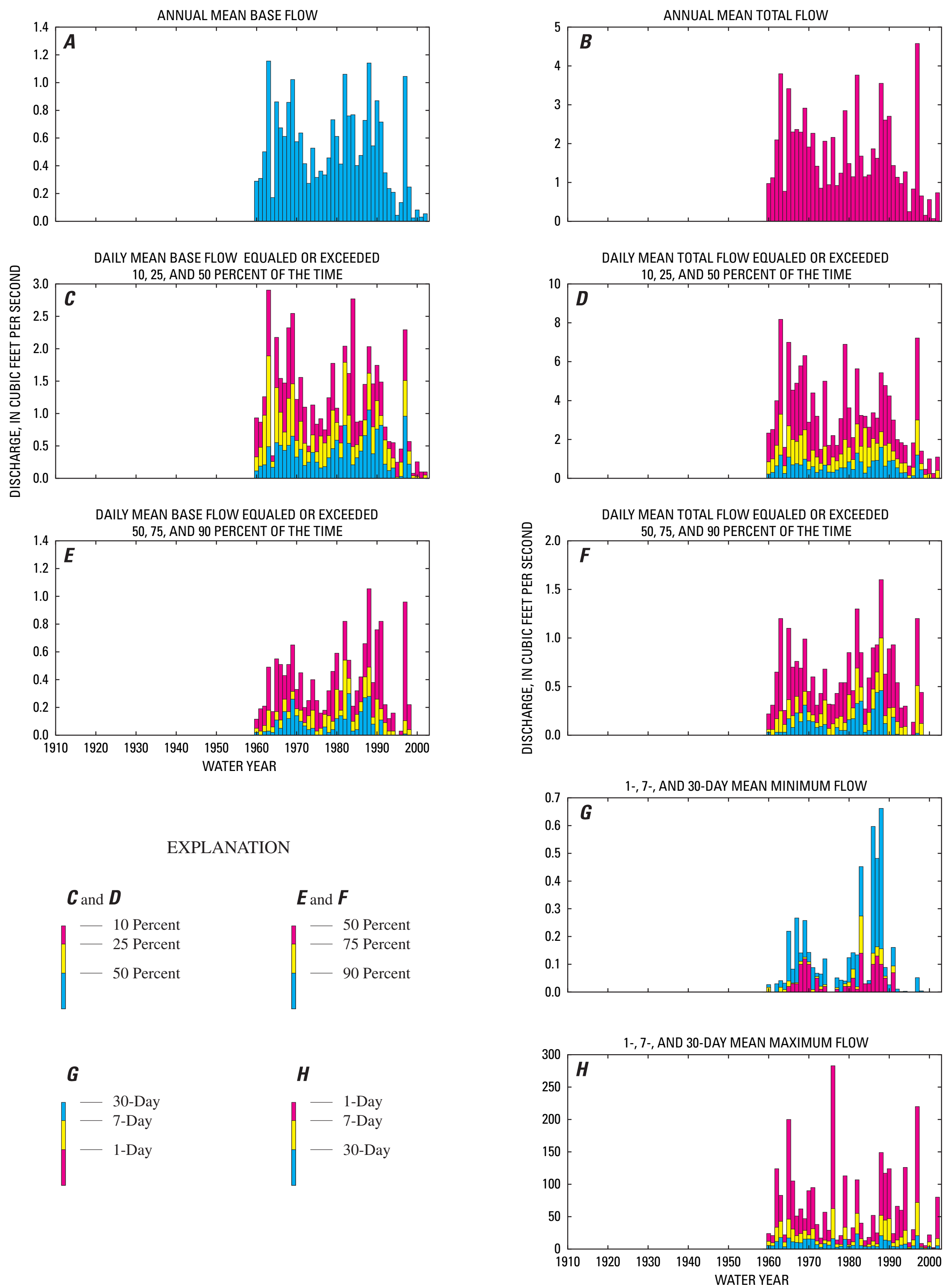

Figure A6. Annual time series for various flow statistics at stream-gaging station 16211600, Makaha Stream near Makaha, Oahu, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

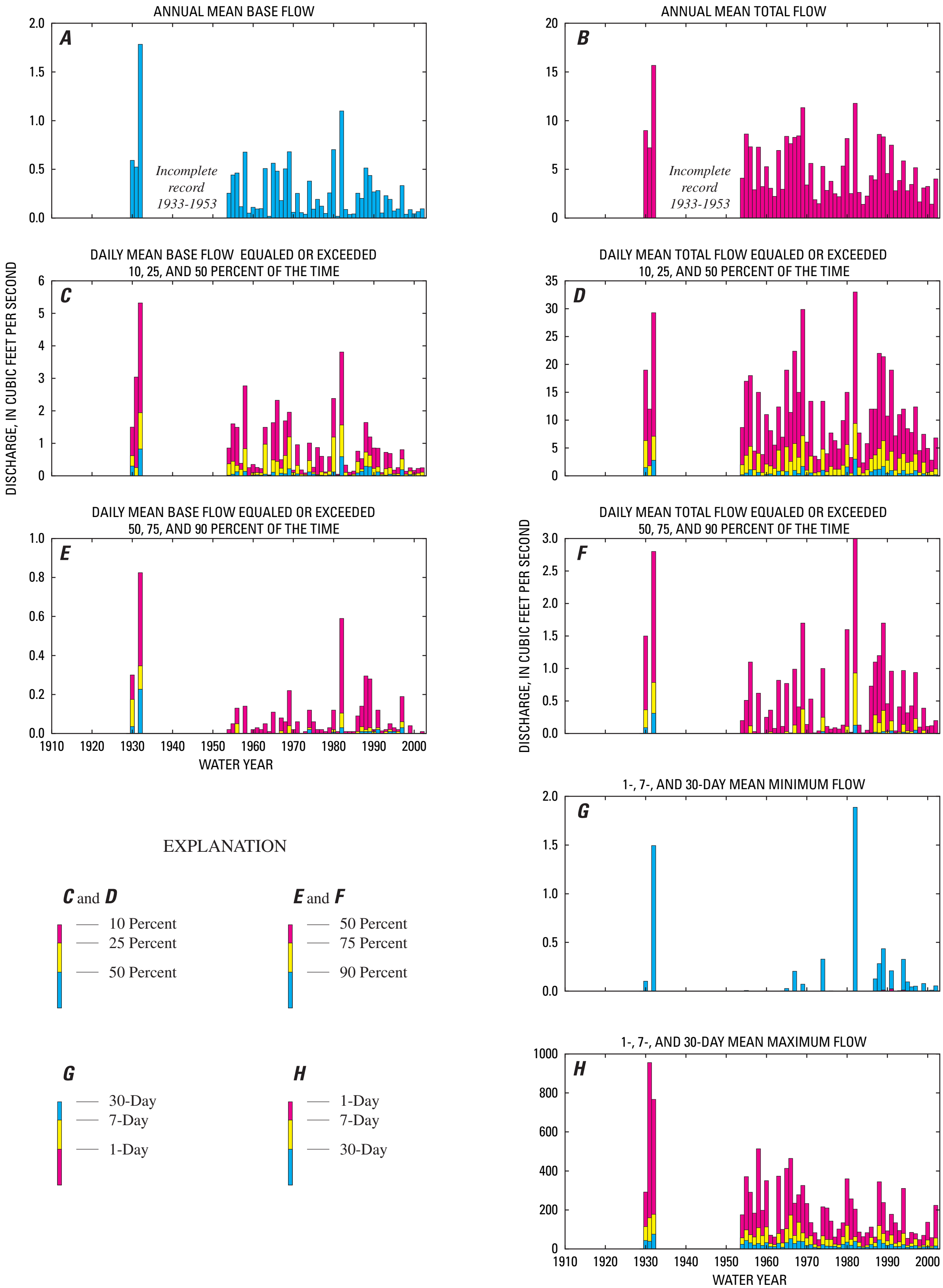

Figure A7. Annual time series for various flow statistics at stream-gaging station 16226000, North Halawa Stream near Honolulu, Oahu, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

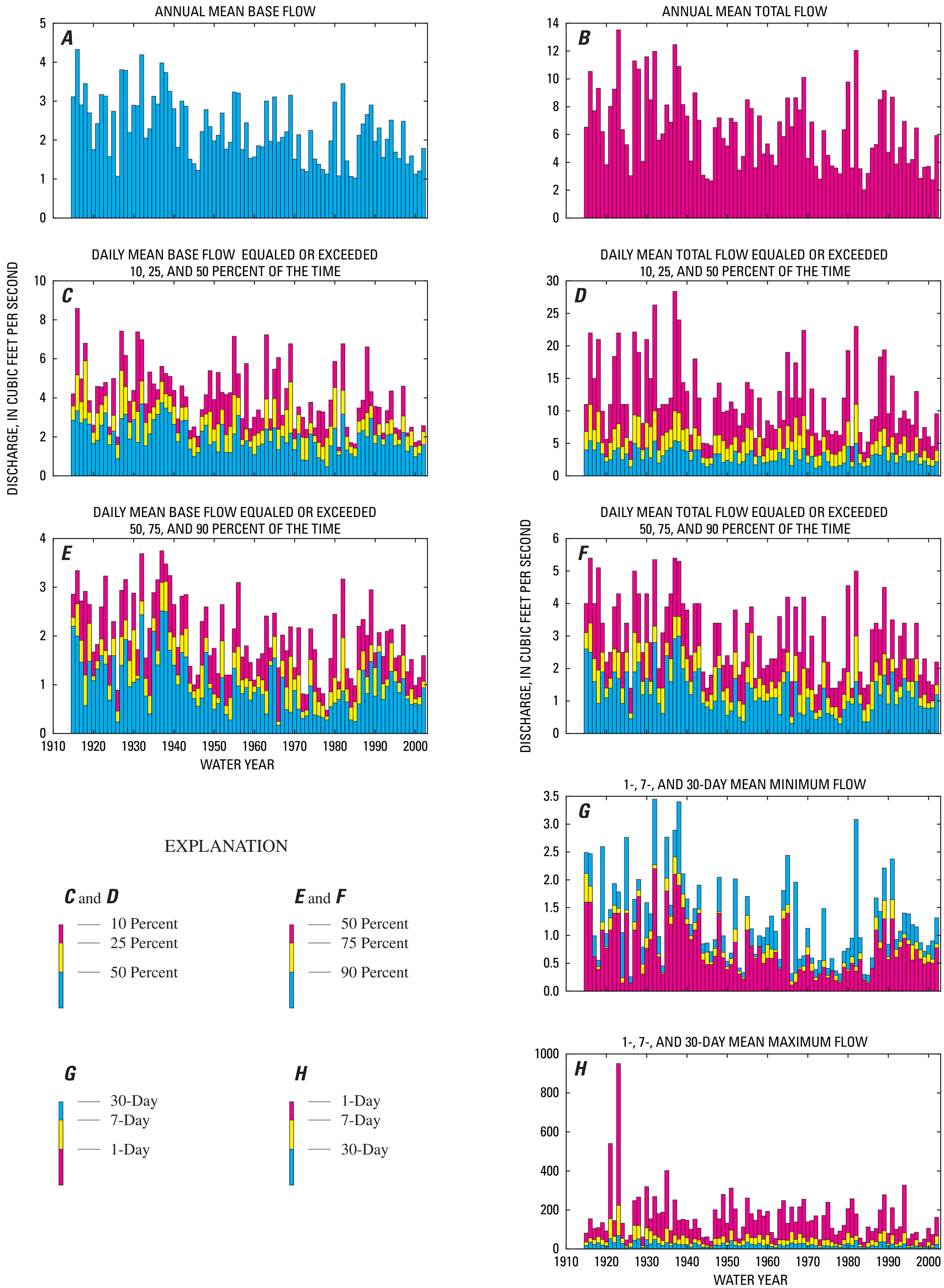

Figure A8. Annual time series for various flow statistics at stream-gaging station 16229000, Kalihi Stream near Honolulu, Oahu, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

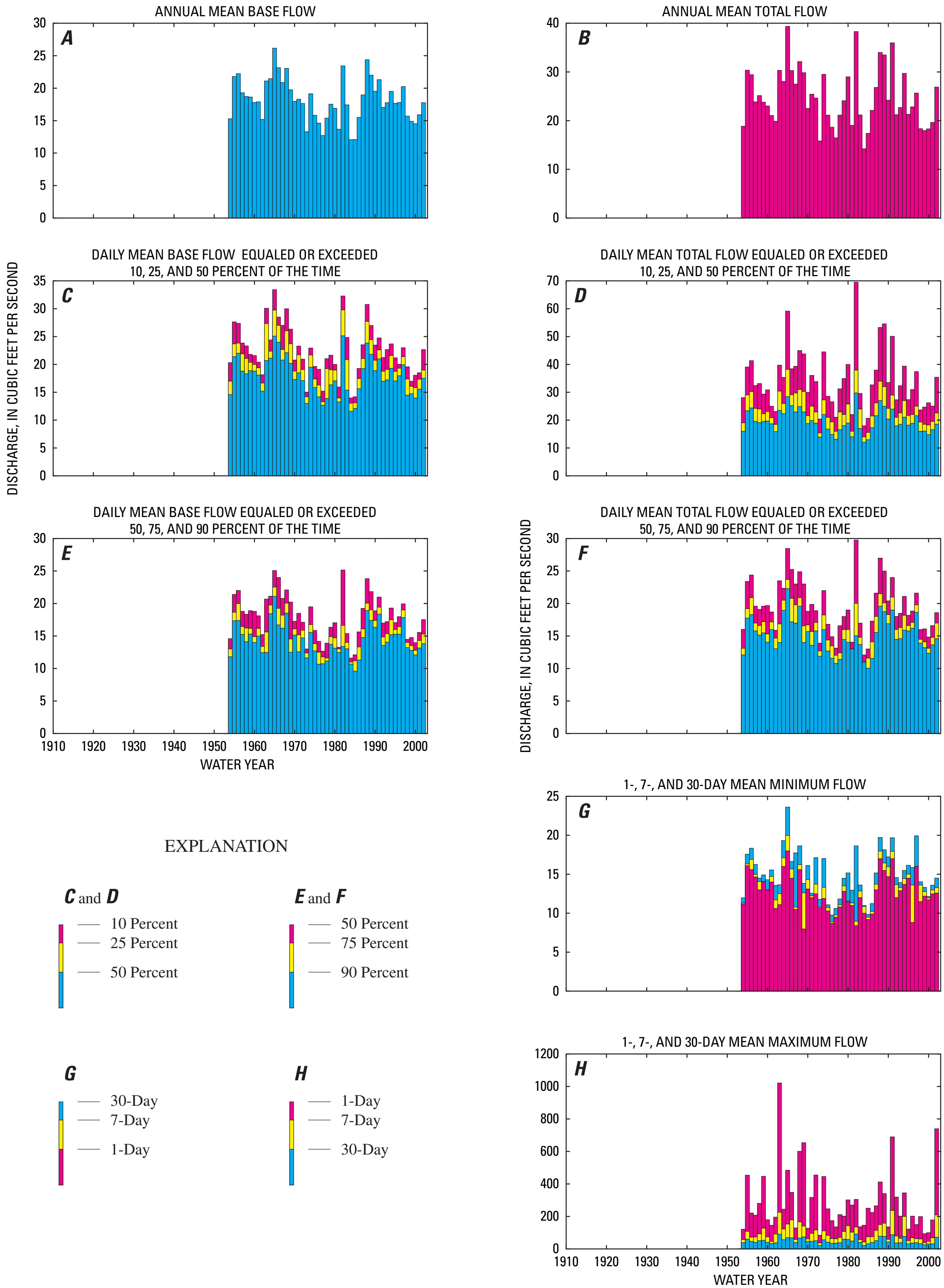

Figure A9. Annual time series for various flow statistics at stream-gaging station 16303003, Punaluu Stream near Punaluu, Oahu, Hawa
water year 2002) of data used.

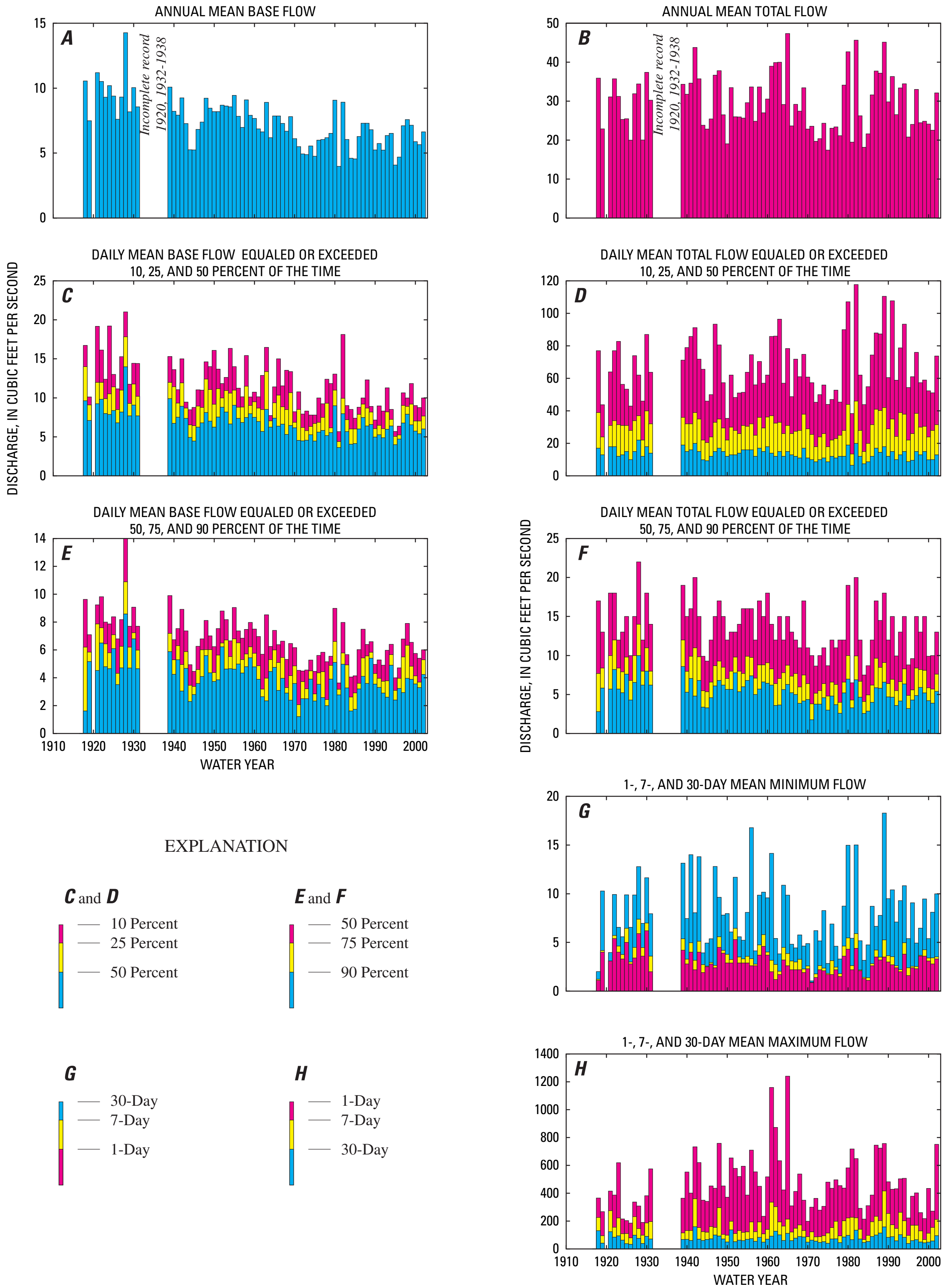

Figure A10. Annual time series for various flow statistics at stream-gaging station 16400000, Halawa Stream near Halawa, Molokai, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

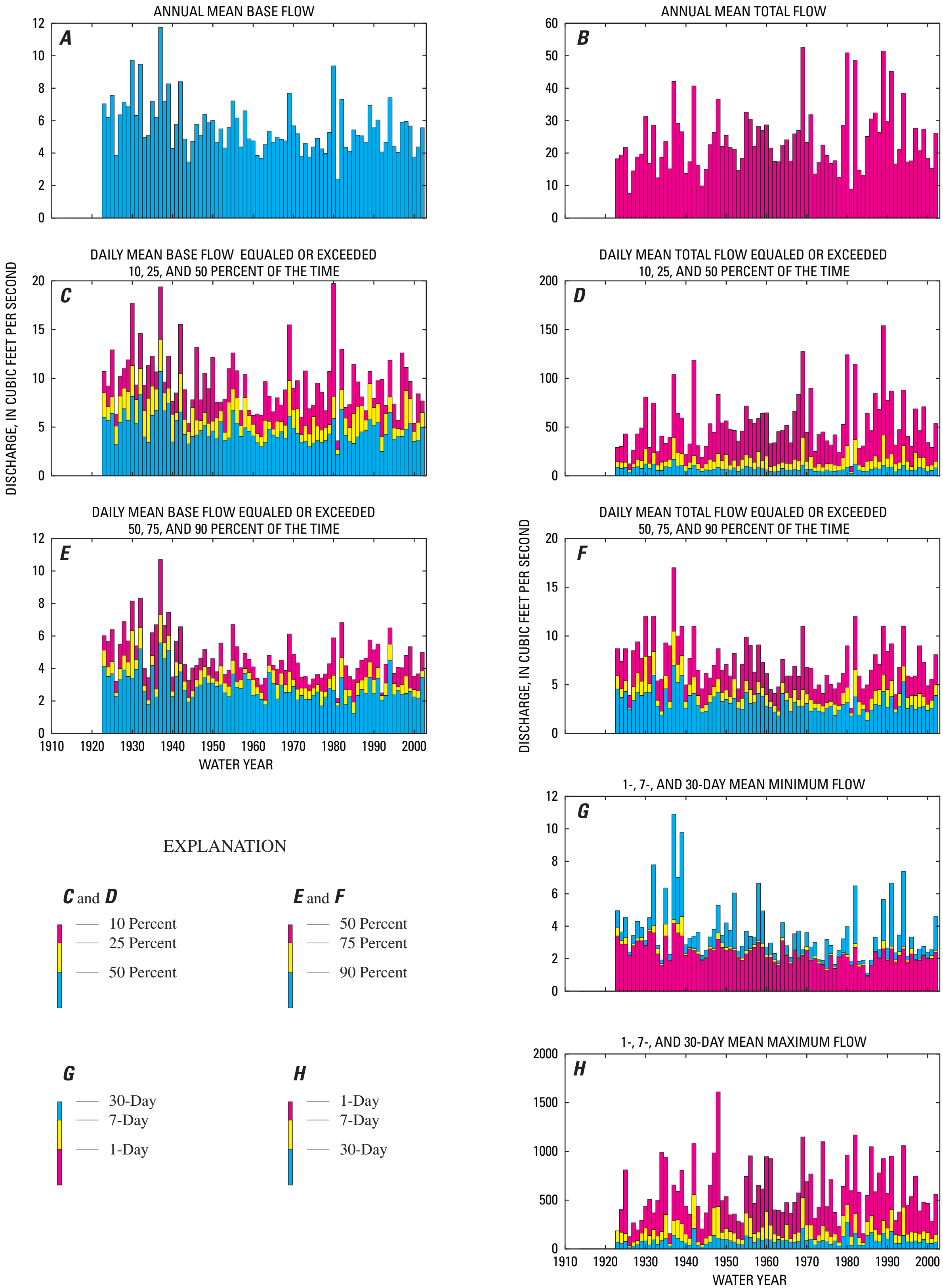

Figure A11. Annual time series for various flow statistics at stream-gaging station 16508000, Hanawi Stream near Nahiku, Maui, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

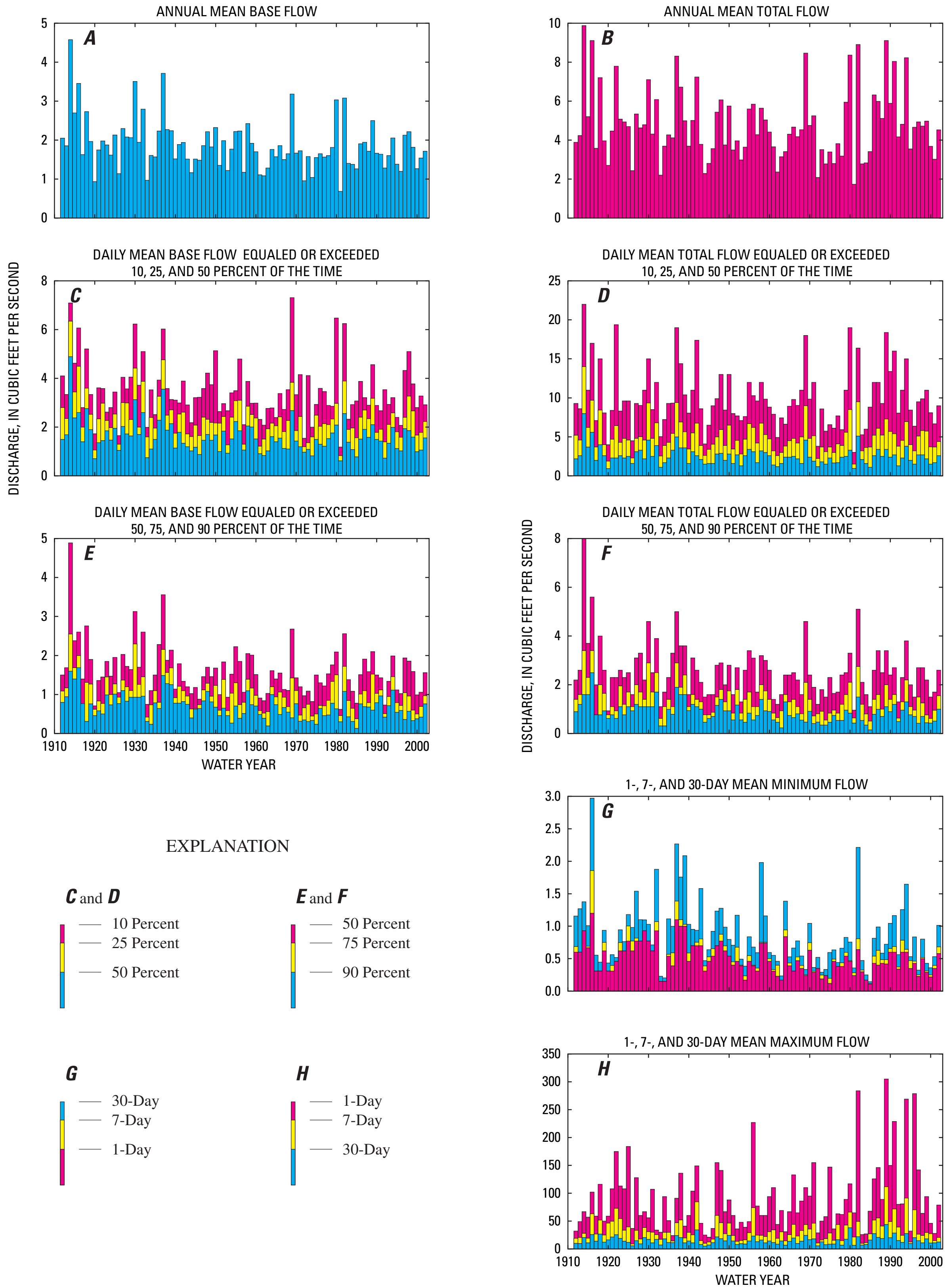

Figure A12. Annual time series for various flow statistics at stream-gaging station 16587000, Honopou Stream near Huelo, Maui, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

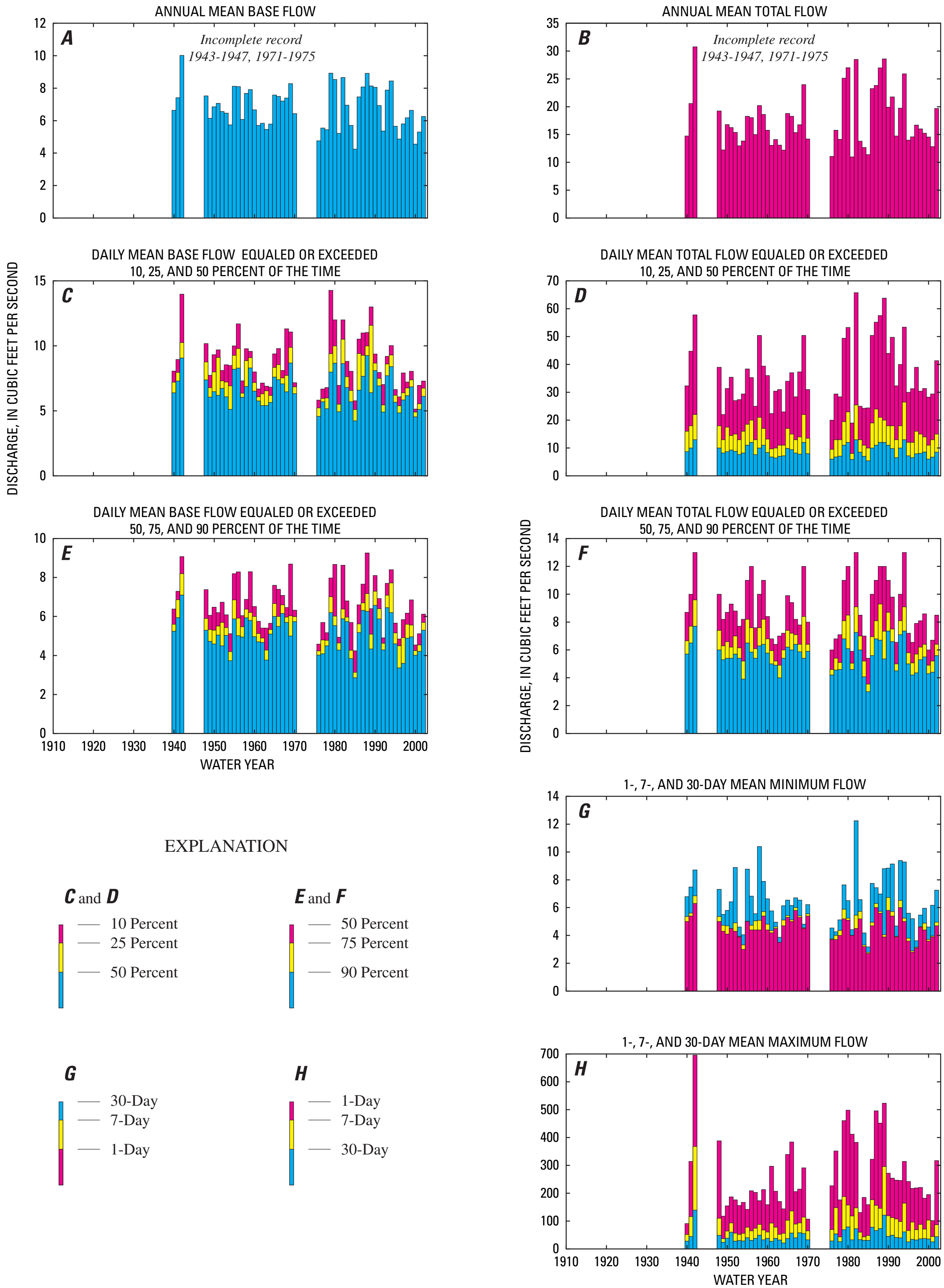

Figure A13. Annual time series for various flow statistics at stream-gaging station 16618000, Kahakuloa Stream near Honokohau, Maui, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

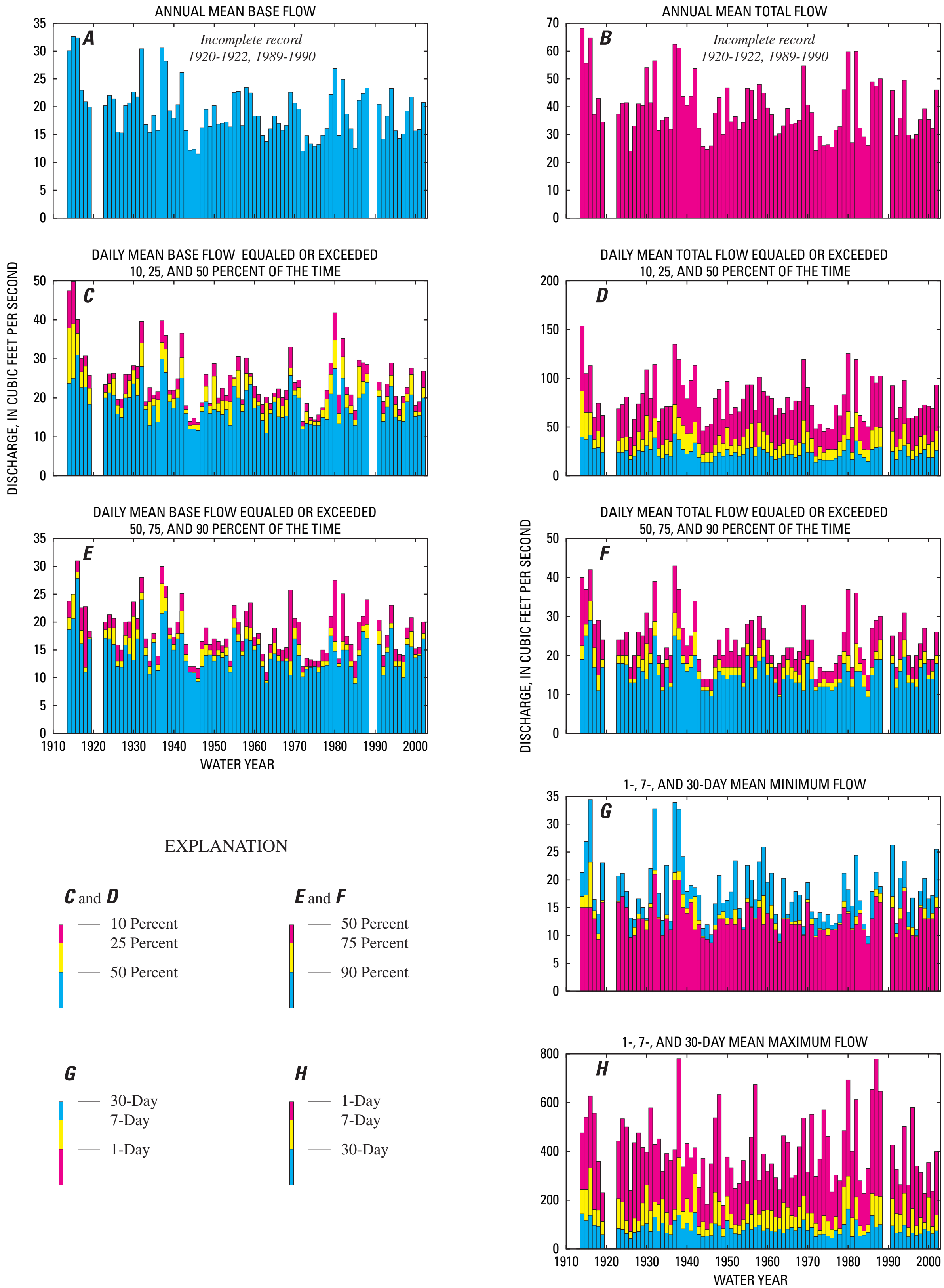

Figure A14. Annual time series for various flow statistics at stream-gaging station 16620000, Honokohau Stream near Honokohau, Maui, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

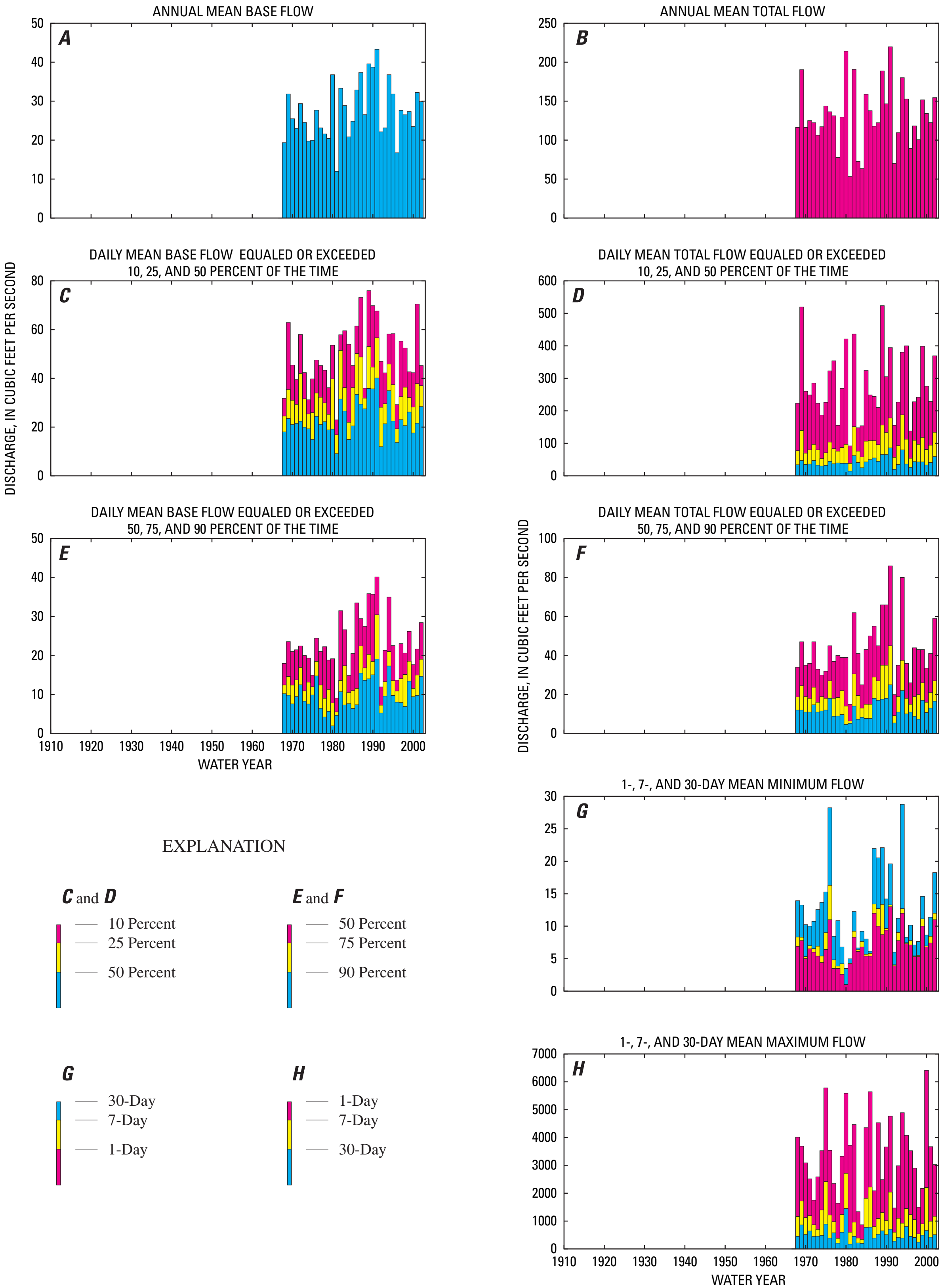

Figure A15. Annual time series for various flow statistics at stream-gaging station 16717000, Honolii Stream near Papaikou, island of Hawaii, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

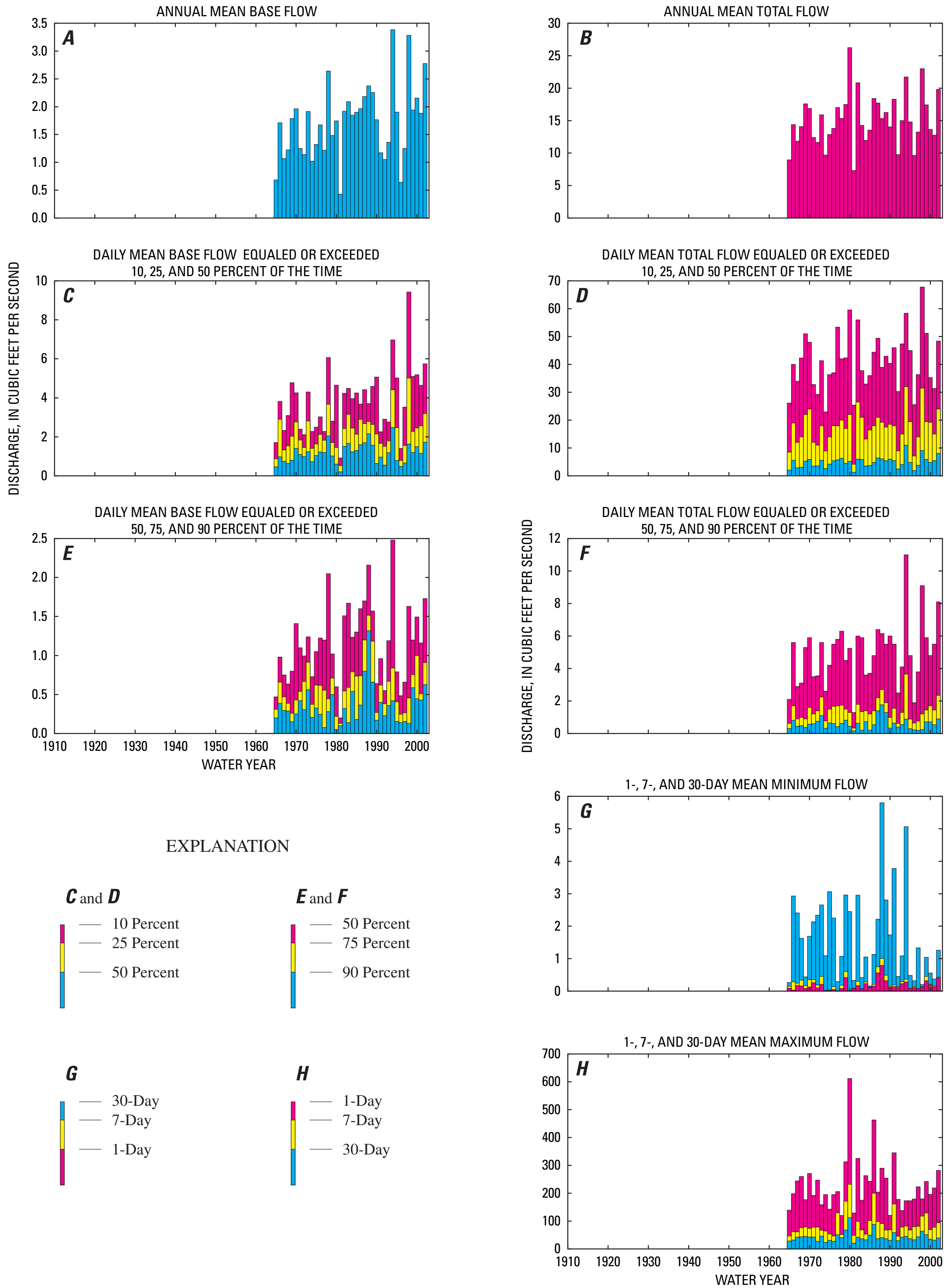

Figure A16. Annual time series for various flow statistics at stream-gaging station 16720000, Kawainui Stream near Kamuela, island of Hawaii, Hawaii. Only complete water years (prior to and including water year 2002) of data used.

Appendix B

Annual Rainfall at Selected Long-Term Rain-Gaging Stations, Hawaii

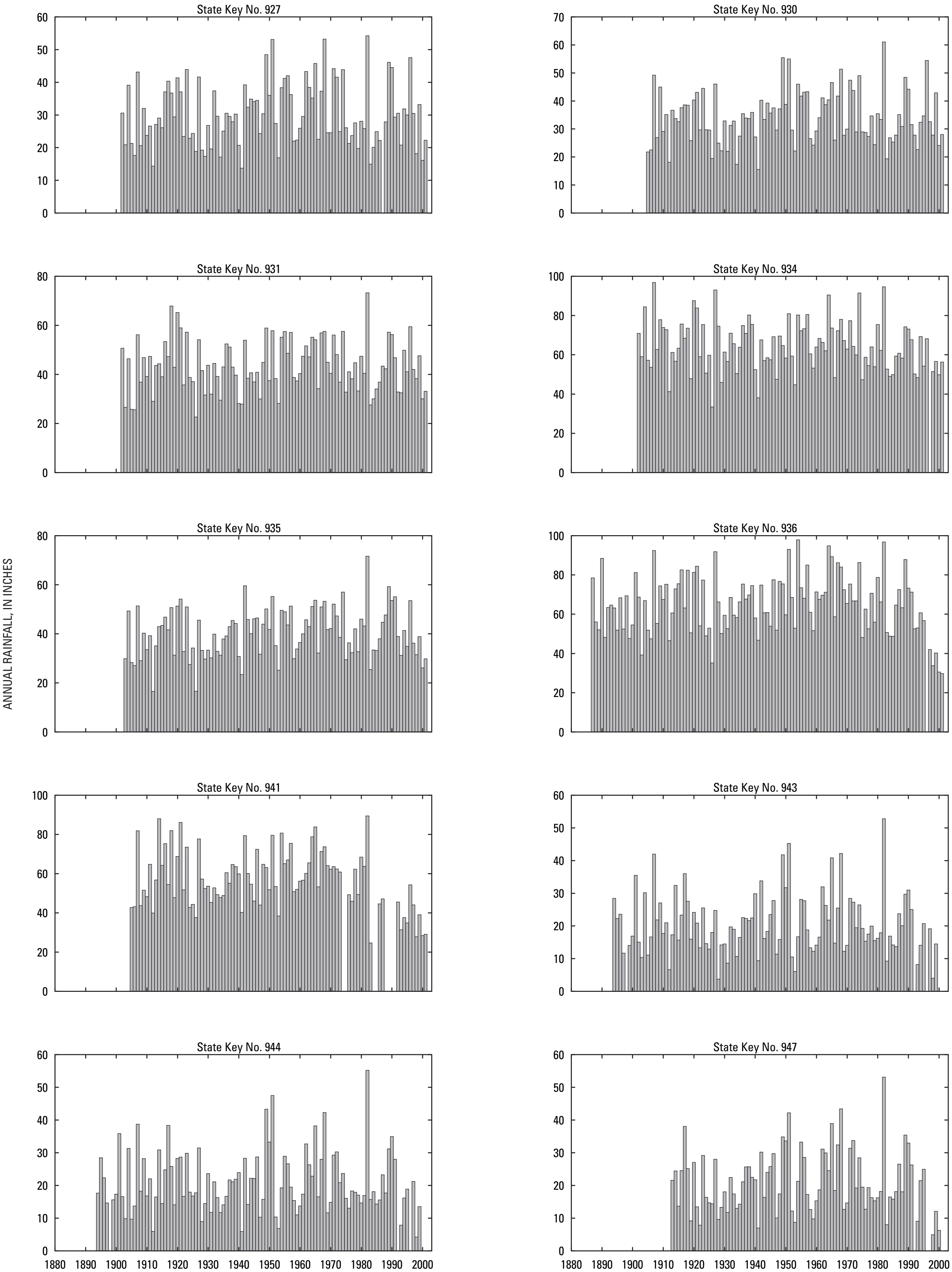

Figure B1. Annual rainfall at selected rain-gaging stations, island of Kauai, Hawaii.

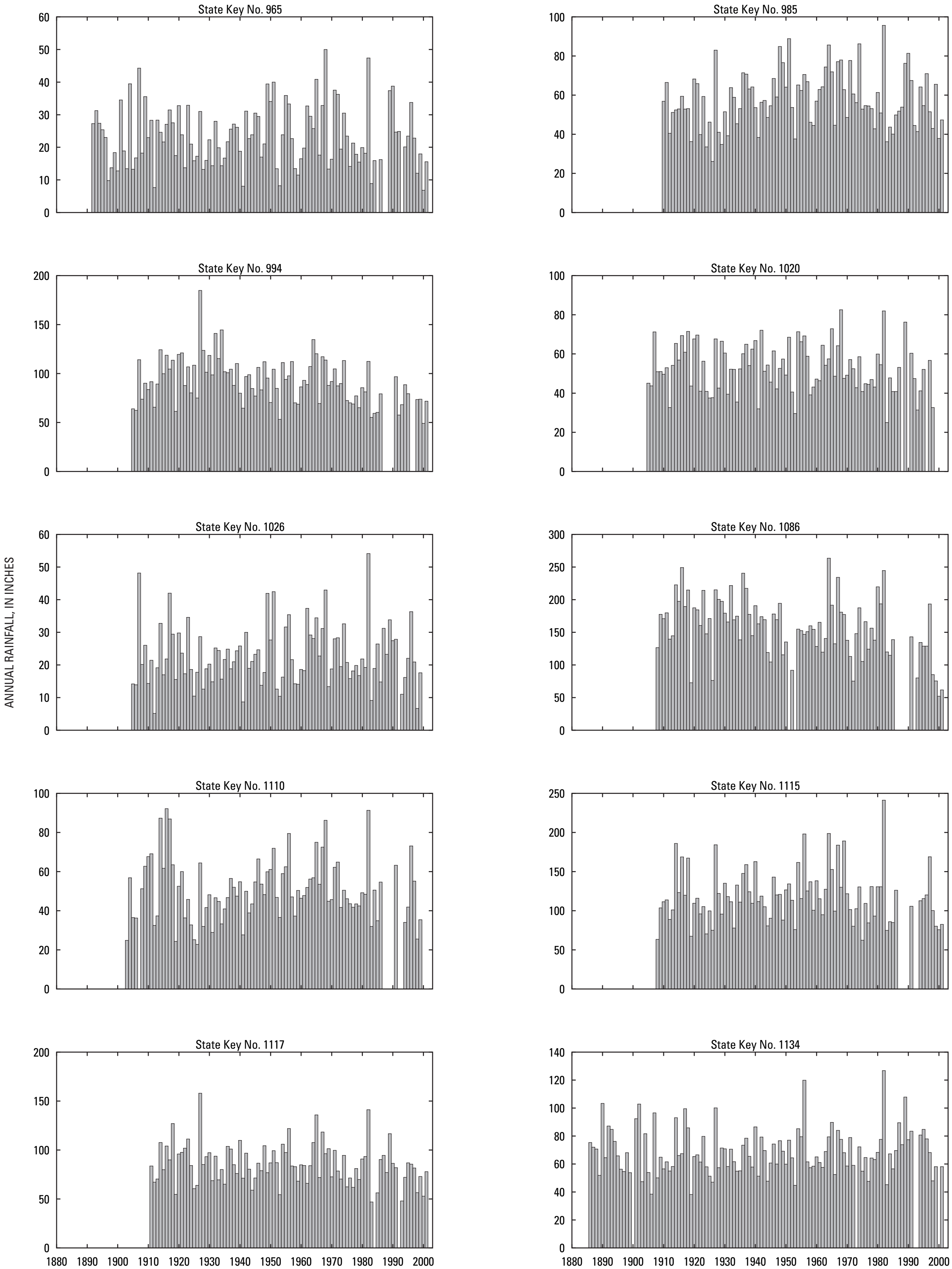

Figure B1. Annual rainfall at selected rain-gaging stations, island of Kauai, Hawaii.–Continued

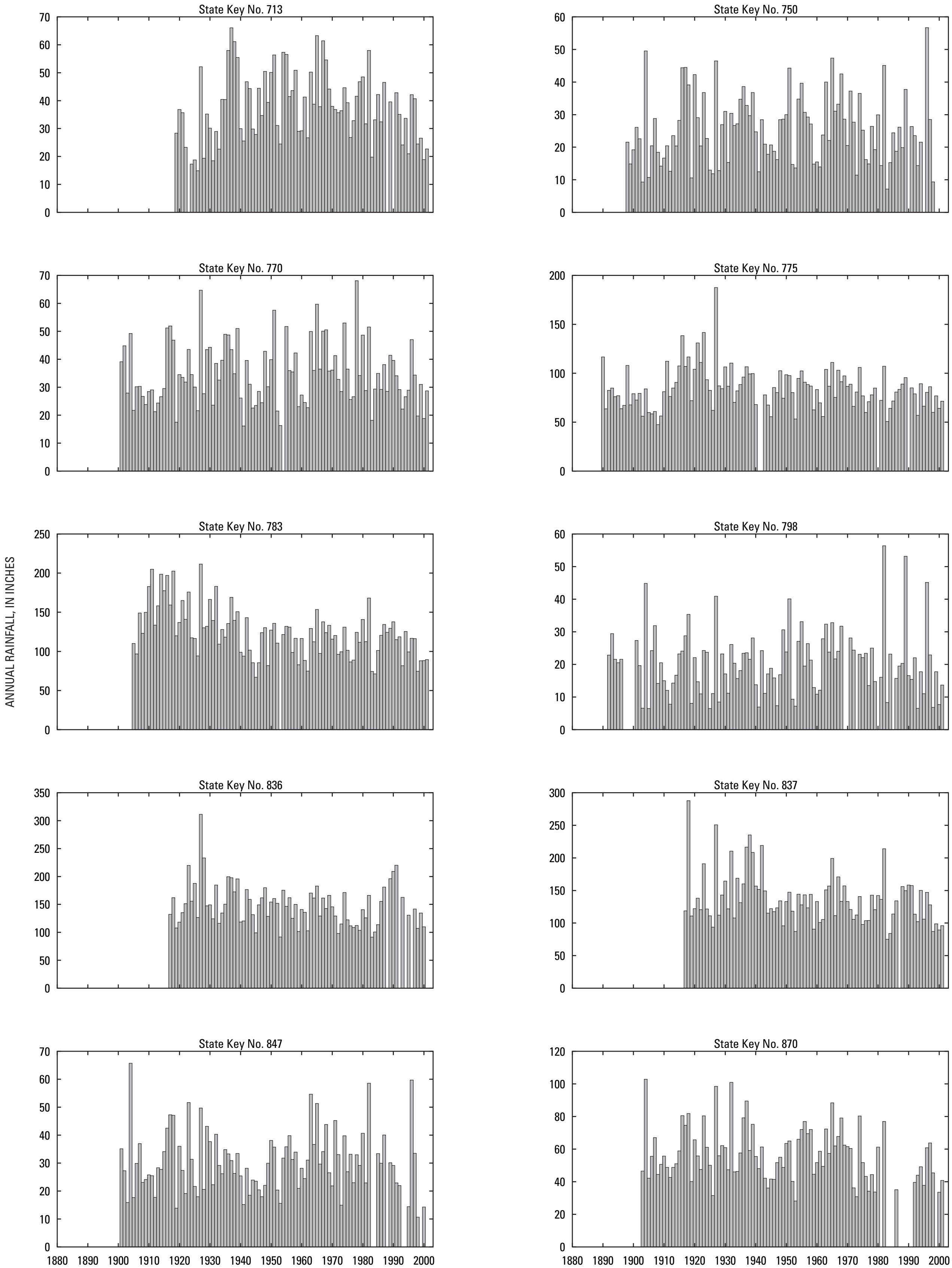

Figure B2. Annual rainfall at selected rain-gaging stations, island of Oahu, Hawaii.

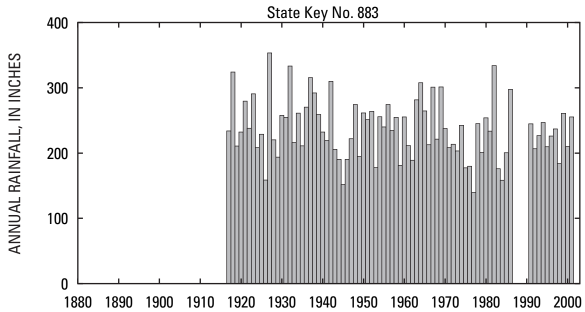

Figure B2. Annual rainfall at selected rain-gaging stations, island of Oahu, Hawaii.–Continued

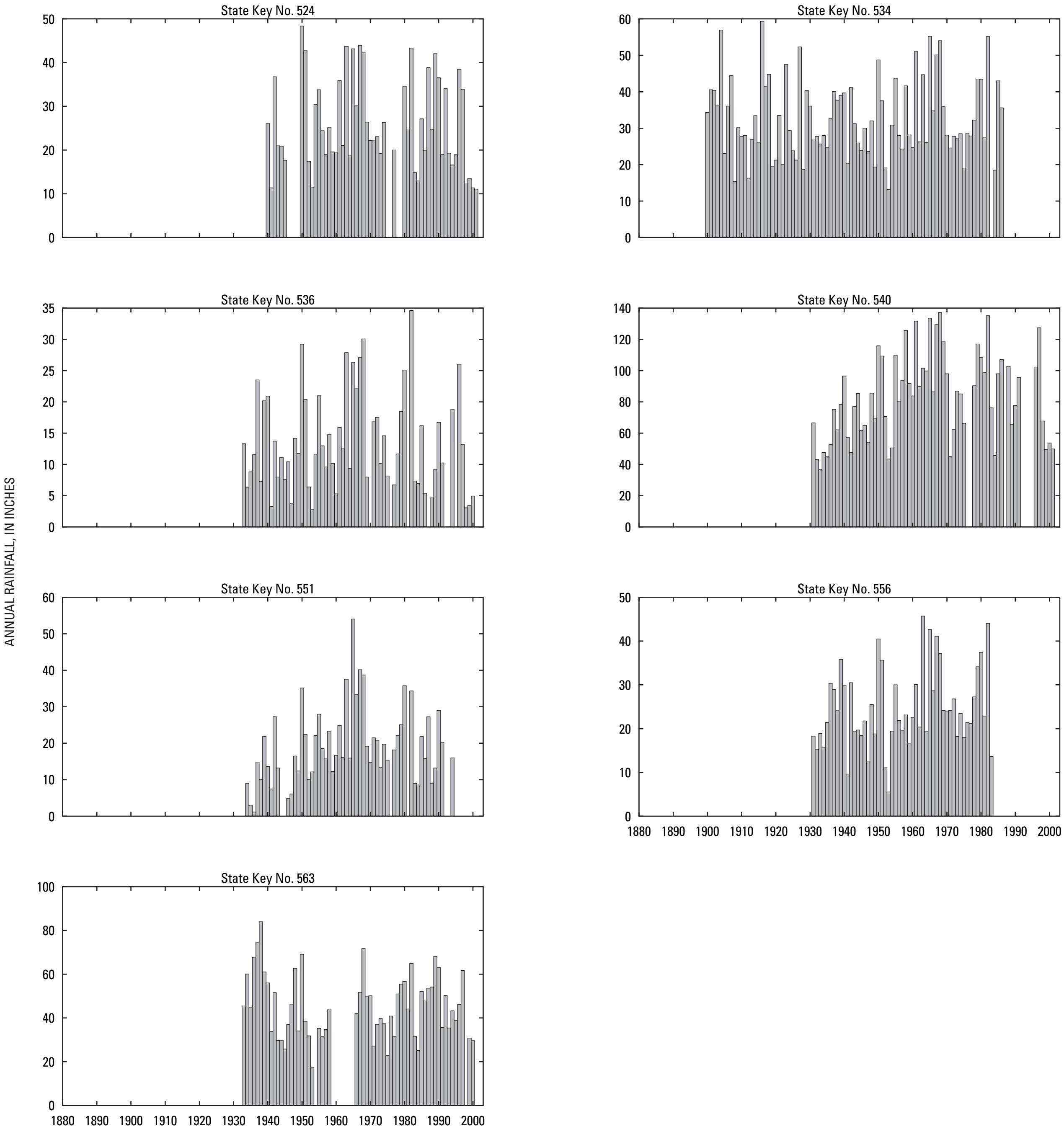

Figure B3. Annual rainfall at selected rain-gaging stations, island of Molokai, Hawaii.

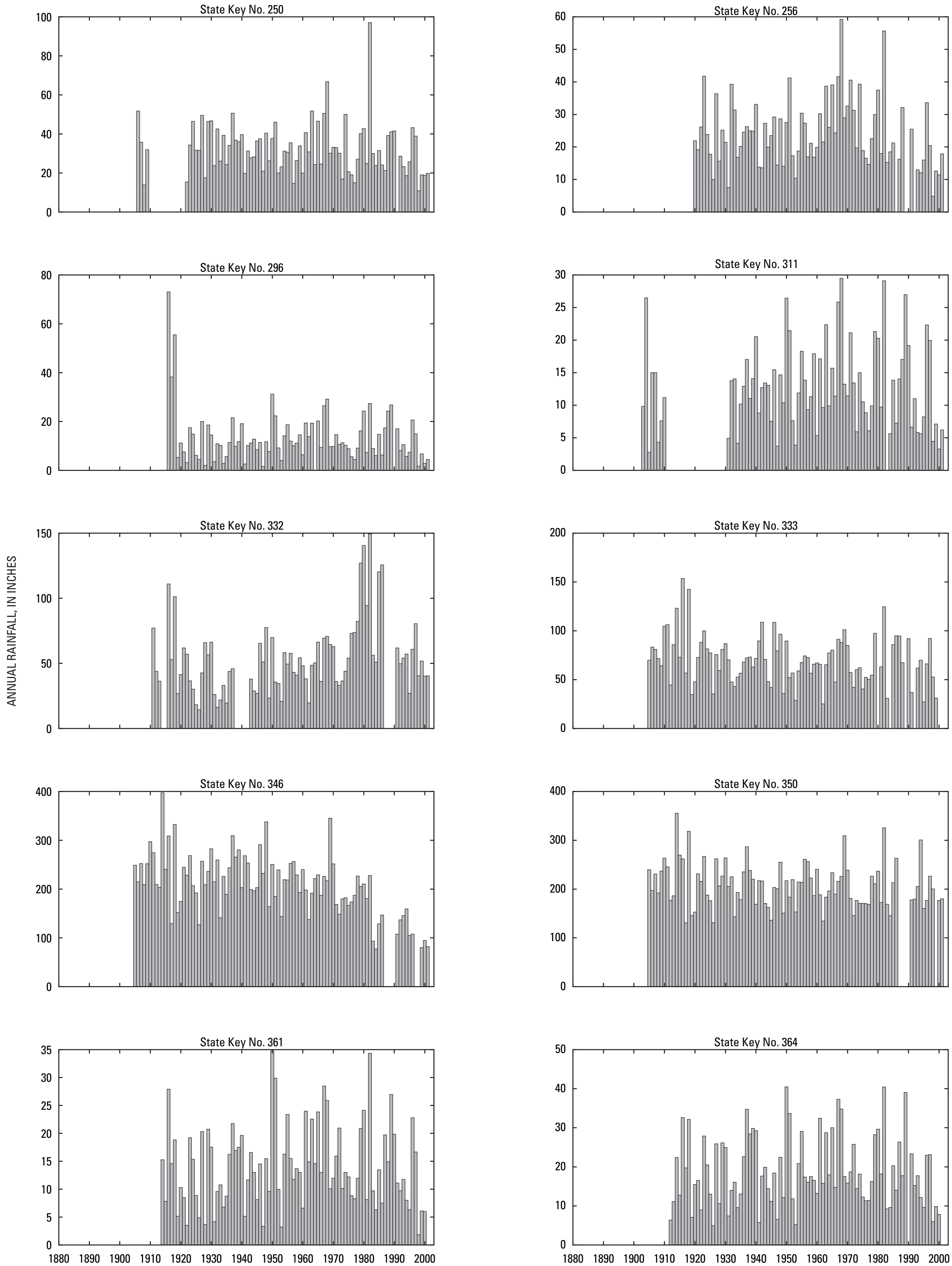

Figure B4. Annual rainfall at selected rain-gaging stations, island of Maui, Hawaii.

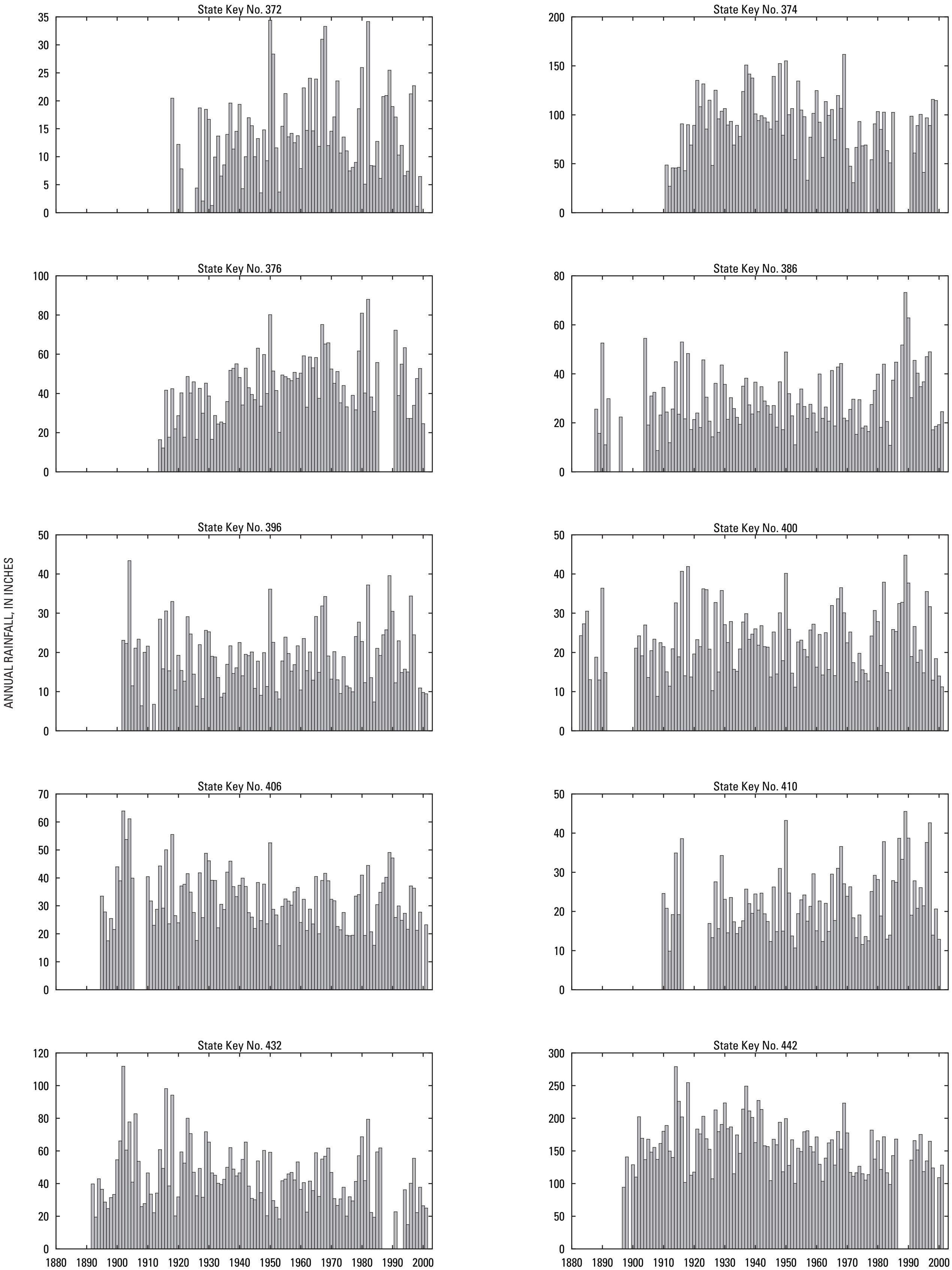

Figure B4. Annual rainfall at selected rain-gaging stations, island of Maui, Hawaii.–Continued

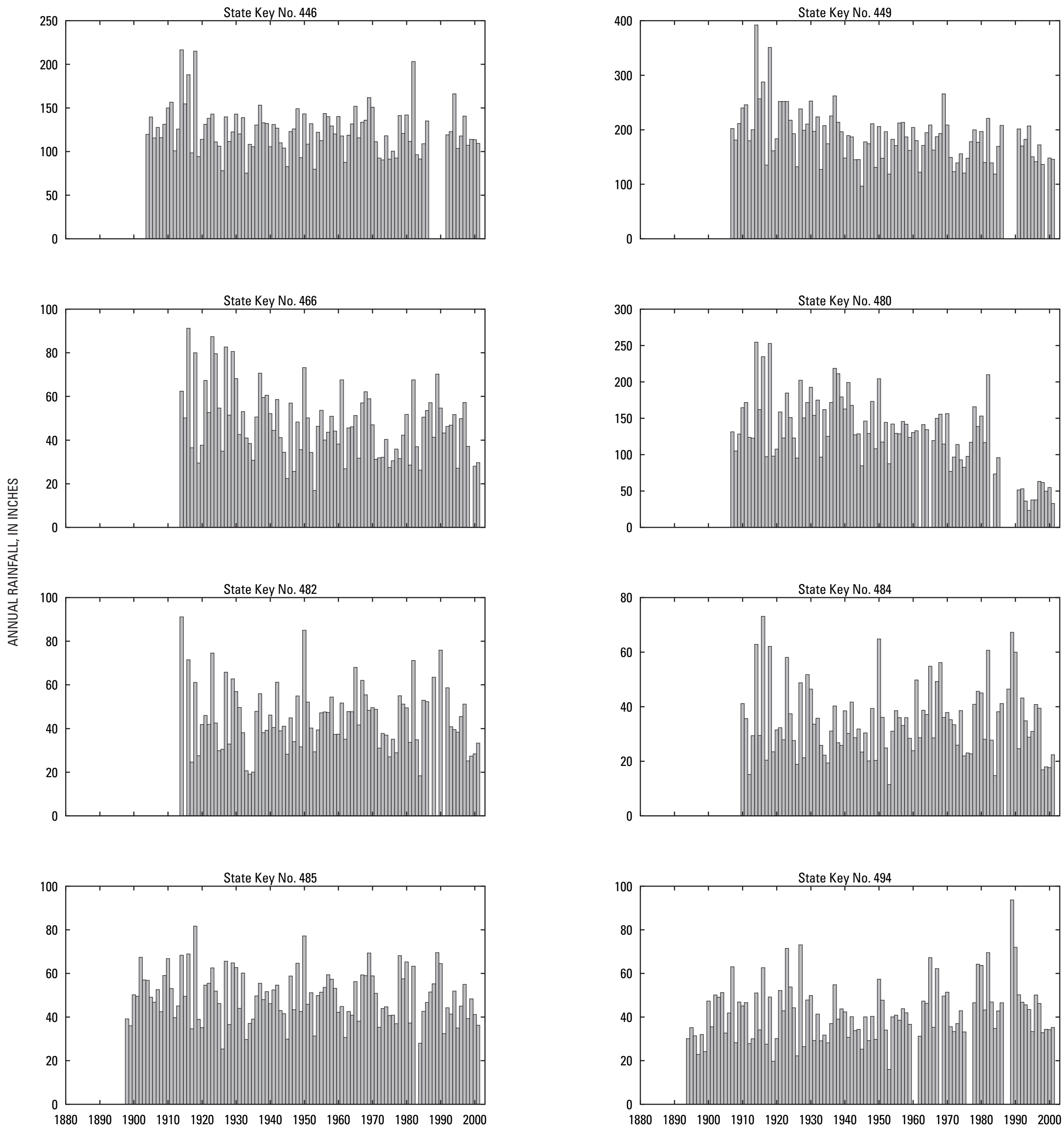

Figure B4. Annual rainfall at selected rain-gaging stations, island of Maui, Hawaii.–Continued

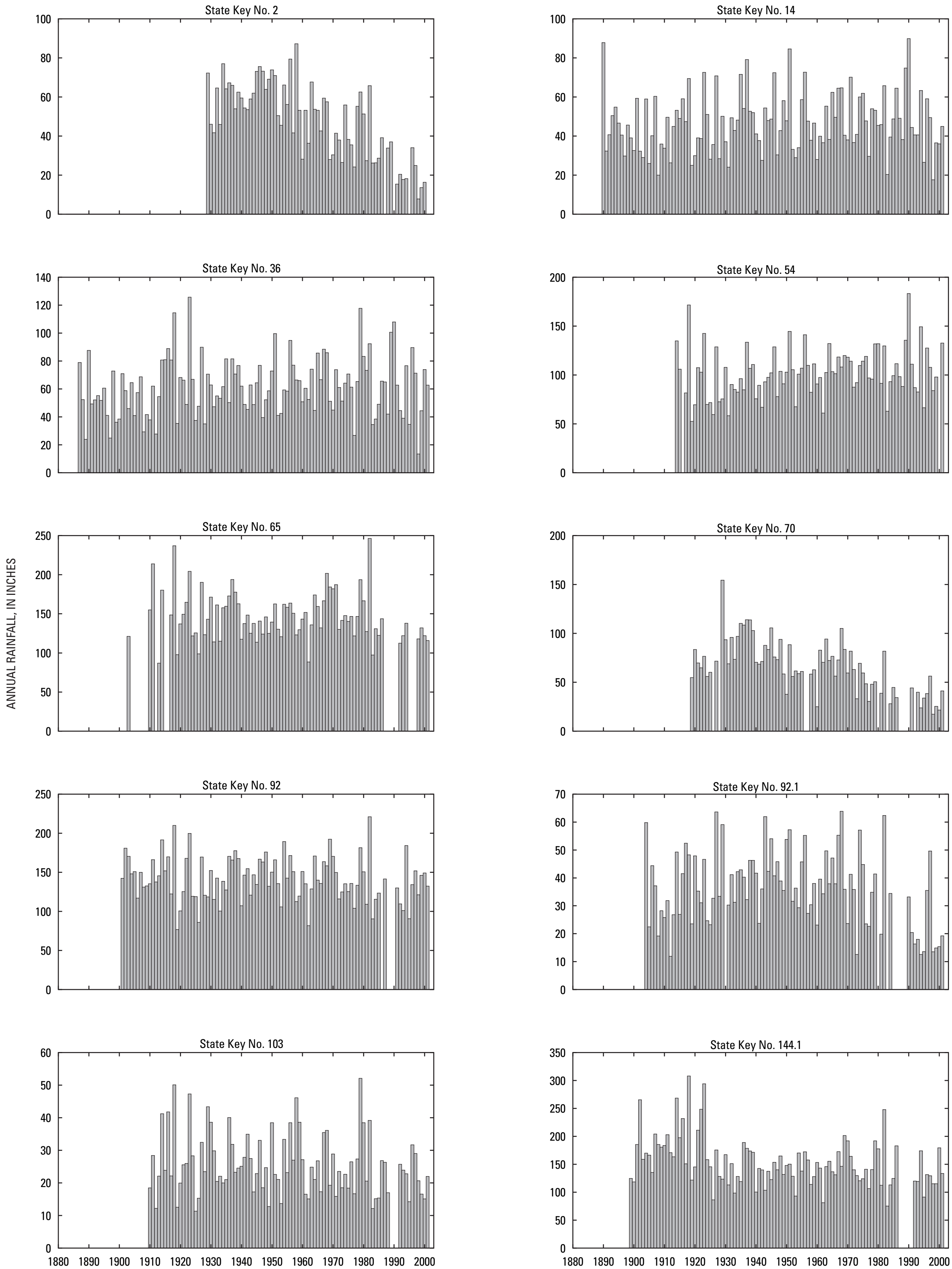

Figure B5. Annual rainfall at selected rain-gaging stations, island of Hawaii, Hawaii.

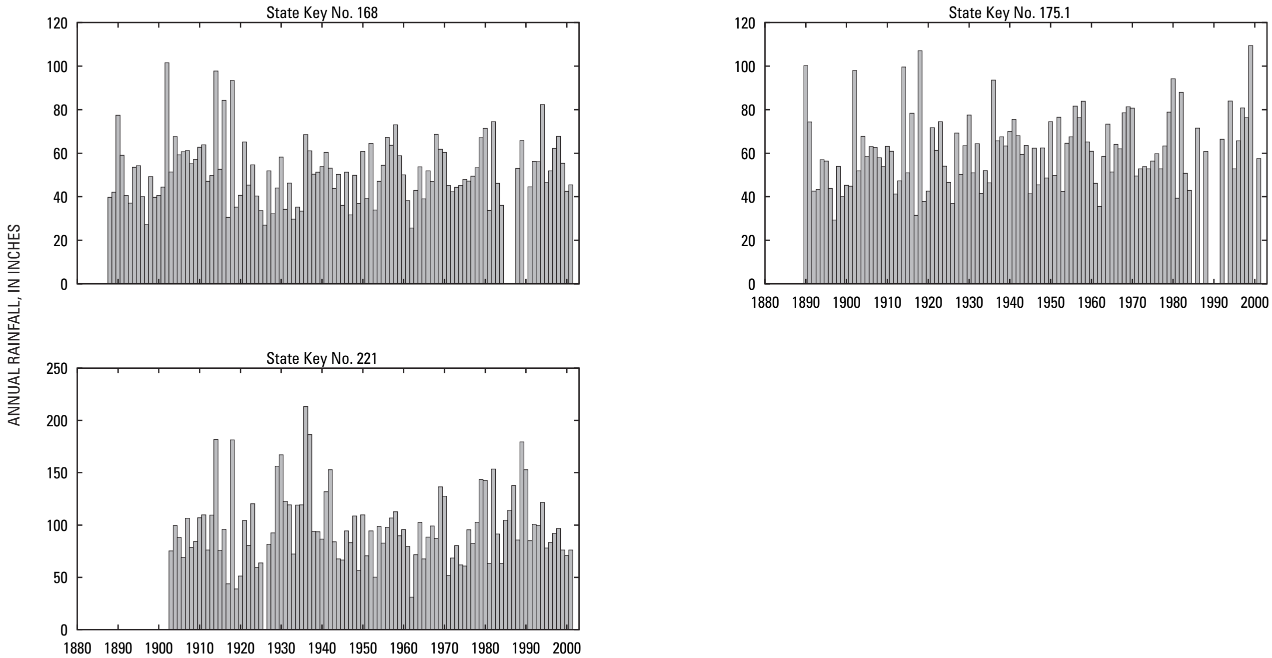

Figure B5. Annual rainfall at selected rain-gaging stations, island of Hawaii, Hawaii.–Continued

Appendix C

Mann-Kendall Test

The Mann-Kendall test is a nonparametric, rank-based statistical test of the relation between two variables and can be used to evaluate trends in hydrologic time-series data if one of the variables is time. Kendall's tau coefficient is used to quantify the strength of the monotonic relation between the two variables, *x* and *y*. If a positive correlation exists (tau>0), the *y* values increase more often than decrease as the *x* values increase; if a negative correlation exists (tau<0), the *y* values decrease more often than increase as the *x* values increase (Helsel and Hirsch, 1992).

For a two-sided test, in which no assumption is made about whether the correlation between *x* and *y* is positive or negative, the null hypothesis, H_0, for the Mann-Kendall test, is that no correlation exists between *x* and *y* (tau=0). The alternate hypothesis, H_1, is that *x* and *y* are correlated (tau $\neq$ 0).

The test statistic, *S*, for the Mann-Kendall test is computed by subtracting the number of discordant pairs of data, (*x*,*y* pairs for which *y* decreases as *x* increases) from concordant pairs (*x*,*y* pairs for which *y* increases as *x* increases). Assuming that the *x* values ($x_1, x_2, \ldots, x_n$) are sorted in ascending order, and each x_i value has an associated y_i value, *S* is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}[(x_j - x_i)(y_j - y_i)] \quad (1)$$

where

S = Mann-Kendall test statistic,

$\operatorname{sgn}[(x_j-x_i)\bullet(y_j-y_i)] = +1$ if $(x_j-x_i)\bullet(y_j-y_i) > 0$,

$\operatorname{sgn}[(x_j-x_i)\bullet(y_j-y_i)] = 0$ if $(x_j-x_i)\bullet(y_j-y_i) = 0$, and

$\operatorname{sgn}[(x_j-x_i)\bullet(y_j-y_i)] = -1$ if $(x_j-x_i)\bullet(y_j-y_i) < 0$.

To compute *S*, a total of $n(n-1)/2$ comparisons between data pairs must be made. The minimum and maximum values of *S*, respectively, are $-n(n-1)/2$ and $n(n-1)/2$. If the *x* values represent time and *S* is a large positive number, then the *y* values tend to increase with time; if *S* is a large negative number, then the *y* values tend to decrease with time.

Kendall's tau coefficient is computed from *S* as follows (Helsel and Hirsch, 1992):

$$\text{tau} = S/[n(n-1)/2] \quad (2)$$

where

n = total number of data pairs.

Because *S* ranges from $-n(n-1)/2$ to $n(n-1)/2$, tau ranges from –1 to +1. Kendall's tau coefficient also can be computed in a manner that accounts for possible ties between data points, in which case the magnitude of tau would be greater than that from equation 2 (see for example Kendall, 1970).

To test the statistical significance of Kendall's tau, the test statistic *S* is compared to the expected value for *S* under the null hypothesis of no correlation. The probability, *p*, of *S* being greater than or equal to (or less than or equal to) the computed value can be determined exactly (see for example Hollander and Wolfe, 1973, table A.21) and compared to the selected level of significance, α. For a two-sided test, the null hypothesis, H_0, is rejected in favor of the alternate hypothesis, H_1, and Kendall's tau is considered significant, if $2p$ is less than α.

For $n<10$, the exact *p*-values should be used to determine statistical significance. For $n \geq 10$, a modified test statistic, *Z*, which is approximately normally distributed can be computed (Kendall, 1970).

$$
\begin{aligned}
Z &= (S-1)/[\mathrm{VAR}(S)]^{1/2} && \text{for } S>0, \\
Z &= 0 && \text{for } S=0, \\
Z &= (S+1)/[\mathrm{VAR}(S)]^{1/2} && \text{for } S<0
\end{aligned}
\qquad (3)
$$

where

Z = modified test statistic,

$$
\begin{aligned}
\mathrm{VAR}(S) = {} & [n(n-1)(2n+5) - \sum_{k=1}^{n_x} t_k(t_k-1)(2t_k+5) - \sum_{l=1}^{n_y} u_l(u_l-1)(2u_l+5)]/18 \\
& + \left[\sum_{k=1}^{n_x} t_k(\;{}_k-1)(t_k-2)\right]\left[\sum_{l=1}^{n_y} u_l(u_l-1)(u_l-2)\right] / \left[9n(n-1)(n-2)\right] \\
& + \left[\sum_{k=1}^{n_x} t_k(t_k-1)\right]\left[\sum_{l=1}^{n_y} u_l(u_l-1)\right] / \left[2n(n-1)\right]
\end{aligned}
$$

t_k = number of tied x values in the k^{th} group of tied x values,

u_l = number of tied y values in the l^{th} group of tied y values,

n_x = number of tied groups of x, and

n_y = number of tied groups of y.

If x represents time, for which no ties exist, then VAR(*S*) reduces to:

$$
\mathrm{VAR}(S) = [n(n-1)(2n+5) - \sum_{l=1}^{n_y} u_l(\;{}_l-1)(2u_l+5)]/18 \qquad (4)
$$

Standard normal distribution tables can be used to evaluate the statistical significance of *Z* provided that $n \geq 10$, unless ties are very extensive or very numerous (Kendall, 1970).

Serial Correlation

Serial correlation in a time series occurs when the observed value from one time period is correlated with and dependent on an observed value from a preceding time period (Haan, 1977). Serial correlation can be positive or negative. Positive serial correlation indicates that, in general, low values follow low values and high values follow high values; negative serial correlation indicates that, in general, low values follow high values and high values follow low values.

Serial correlation is common in hydrologic time series, particularly for short time scales. Because the Mann-Kendall test requires serially independent data, serial correlation in hydrologic time series can confound use of the Mann-Kendall test to detect trends. If the Mann-Kendall test is used to detect trends in a time series with positive serial correlation, a statistically significant trend may be detected even though no trend exists; if the Mann-Kendall test is used to detect trends in a time series with negative serial correlation, no trend may be detected even though a trend does exist (Yue and Wang, 2002). Hirsch and Slack (1984) developed an extension of the Mann-Kendall test to account for serial dependence in seasonal hydrologic time series. For two seasons, Hirsch and others (1982) define the test statistic, S', as follows:

$$S' = S_1 + S_2 \qquad (5)$$

where

S_1 = test statistic, S, for season 1, and

S_2 = test statistic, S, for season 2.

The modified test statistic, Z', that is approximately normally distributed is (Hirsch and others, 1982):

$$Z' = (S'-1)/[\mathrm{VAR}(S')]^{1/2} \quad \text{for } S'>0,$$
$$Z' = 0 \quad \text{for } S'=0,$$
$$Z' = (S'+1)/[\mathrm{VAR}(S')]^{1/2} \quad \text{for } S'<0 \qquad (6)$$

where

$$\mathrm{VAR}(S') = \mathrm{VAR}(S_1) + \mathrm{VAR}(S_2) + \mathrm{COV}(S_1,S_2).$$

Hirsch and Slack (1984) describe the computation of $\mathrm{COV}(S_1,S_2)$.

Trend tests for this study used a modified version of the seasonal Mann-Kendall test (Hirsch and Slack, 1984) by treating each series and its associated 1-year lagged series as "seasons." To ensure that the modified seasonal Mann-Kendall test reduced to the Mann-Kendall test in the absence of serial correlation (that is, if $\mathrm{COV}(S_1,S_2)$ is equal to zero), S' and $\mathrm{VAR}(S')$ were each divided by a factor of 2. Division by a factor of 2 is consistent with fact that the seasonal Mann-Kendall test is being used to account for autocorrelation within a single annual time series rather than correlation between two separate time series.

Appendix D

Tables 2–5

Table 2. Results of Mann-Kendall test for trends in annual flows during 1913 to 2002 at long-term-trend stations, Hawaii.

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16068000	**Q_{90} (total flow)**	**16**	**87**	**-0.211**	**-0.055**	**0.004**	**0.009**	**0.124**	**0.095**
16068000	**Q_{75} (total flow)**	**22**	**87**	**-0.208**	**-0.060**	**0.004**	**0.007**	**0.070**	**0.347**
16068000	**Q_{50} (total flow)**	**31**	**87**	**-0.163**	**-0.059**	**0.025**	**0.024**	**-0.038**	**0.614**
16068000	Q_{25} (total flow)	48	87	-0.083	-0.052	0.255	0.209	-0.058	0.434
16068000	Q_{10} (total flow)	84	87	-0.018	-0.021	0.809	0.709	-0.002	0.985
16068000	Mean (total flow)	48.0	87	-0.050	-0.040	0.495	0.415	0.011	0.886
16068000	**Q_{90} (base flow)**	**14**	**87**	**-0.195**	**-0.048**	**0.008**	**0.014**	**0.147**	**0.048**
16068000	**Q_{75} (base flow)**	**18**	**87**	**-0.207**	**-0.053**	**0.005**	**0.009**	**0.115**	**0.121**
16068000	**Q_{50} (base flow)**	**23**	**87**	**-0.178**	**-0.045**	**0.015**	**0.025**	**0.076**	**0.306**
16068000	Q_{25} (base flow)	30	87	-0.126	-0.047	0.084	0.093	0.052	0.484
16068000	**Q_{10} (base flow)**	**38**	**87**	**-0.151**	**-0.063**	**0.038**	**0.046**	**0.071**	**0.340**
16068000	**Mean (base flow)**	**25.4**	**87**	**-0.184**	**-0.052**	**0.012**	**0.016**	**0.068**	**0.360**
16068000	1-day minimum	7.00	87	-0.140	-0.026	0.054	0.067	0.162	0.028
16068000	**7-day minimum**	**7.43**	**87**	**-0.190**	**-0.044**	**0.009**	**0.022**	**0.151**	**0.042**
16068000	**30-day minimum**	**7.94**	**87**	**-0.195**	**-0.065**	**0.008**	**0.011**	**0.067**	**0.372**
16068000	1-day maximum	2570	87	0.090	2.143	0.217	0.358	0.145	0.052
16068000	7-day maximum	1840	87	0.074	0.566	0.312	0.456	0.157	0.035
16068000	30-day maximum	1290	87	0.072	0.208	0.322	0.440	0.193	0.009
16200000	Q_{90} (total flow)	1.7	79	-0.104	-0.006	0.178	0.155	0.000	1.000
16200000	Q_{75} (total flow)	3.4	79	-0.152	-0.013	0.048	0.052	0.066	0.404
16200000	**Q_{50} (total flow)**	**7.1**	**79**	**-0.189**	**-0.026**	**0.014**	**0.014**	**0.010**	**0.904**
16200000	Q_{25} (total flow)	16	79	-0.135	-0.033	0.079	0.082	-0.007	0.935
16200000	Q_{10} (total flow)	36	79	-0.058	-0.037	0.448	0.433	0.016	0.843
16200000	Mean (total flow)	16.2	79	-0.146	-0.037	0.057	0.052	0.011	0.889
16200000	Q_{90} (base flow)	0.94	79	-0.097	-0.005	0.207	0.180	-0.029	0.716
16200000	Q_{75} (base flow)	2.1	79	-0.122	-0.008	0.113	0.116	0.044	0.581
16200000	**Q_{50} (base flow)**	**3.7**	**79**	**-0.227**	**-0.018**	**0.003**	**0.006**	**0.111**	**0.156**
16200000	**Q_{25} (base flow)**	**5.8**	**79**	**-0.292**	**-0.028**	**0.000**	**0.000**	**0.072**	**0.360**
16200000	**Q_{10} (base flow)**	**8.7**	**79**	**-0.368**	**-0.048**	**0.000**	**0.000**	**0.169**	**0.031**
16200000	**Mean (base flow)**	**4.38**	**79**	**-0.318**	**-0.024**	**0.000**	**0.000**	**0.149**	**0.058**
16200000	1-day minimum	0.12	79	-0.087	-0.002	0.258	0.216	-0.036	0.644
16200000	7-day minimum	0.13	79	-0.121	-0.004	0.114	0.091	-0.038	0.634
16200000	30-day minimum	0.14	79	-0.061	-0.006	0.431	0.384	-0.049	0.533
16200000	1-day maximum	975	79	-0.086	-0.685	0.266	0.250	0.112	0.152
16200000	**7-day maximum**	**861**	**79**	**-0.172**	**-0.414**	**0.025**	**0.026**	**0.086**	**0.276**
16200000	**30-day maximum**	**593**	**79**	**-0.185**	**-0.161**	**0.016**	**0.015**	**0.015**	**0.847**

Table 2. Results of Mann-Kendall test for trends in annual flows during 1913 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16229000	**Q_{90} (total flow)**	**0.96**	**88**	**-0.256**	**-0.009**	**0.000**	**0.001**	**0.192**	**0.008**
16229000	**Q_{75} (total flow)**	**1.6**	**88**	**-0.278**	**-0.012**	**0.000**	**0.000**	**0.145**	**0.047**
16229000	**Q_{50} (total flow)**	**2.8**	**88**	**-0.269**	**-0.016**	**0.000**	**0.001**	**0.121**	**0.097**
16229000	**Q_{25} (total flow)**	**5.4**	**88**	**-0.257**	**-0.034**	**0.000**	**0.001**	**0.138**	**0.058**
16229000	**Q_{10} (total flow)**	**11**	**88**	**-0.230**	**-0.070**	**0.002**	**0.004**	**0.137**	**0.060**
16229000	**Mean (total flow)**	**6.36**	**88**	**-0.255**	**-0.041**	**0.000**	**0.002**	**0.170**	**0.020**
16229000	**Q_{90} (base flow)**	**0.72**	**88**	**-0.278**	**-0.009**	**0.000**	**0.001**	**0.219**	**0.003**
16229000	**Q_{75} (base flow)**	**1.2**	**88**	**-0.284**	**-0.010**	**0.000**	**0.001**	**0.194**	**0.008**
16229000	**Q_{50} (base flow)**	**1.9**	**88**	**-0.298**	**-0.014**	**0.000**	**0.000**	**0.199**	**0.006**
16229000	**Q_{25} (base flow)**	**3.0**	**88**	**-0.322**	**-0.019**	**0.000**	**0.000**	**0.192**	**0.008**
16229000	**Q_{10} (base flow)**	**4.3**	**88**	**-0.292**	**-0.026**	**0.000**	**0.000**	**0.112**	**0.125**
16229000	**Mean (base flow)**	**2.28**	**88**	**-0.338**	**-0.017**	**0.000**	**0.000**	**0.211**	**0.004**
16229000	**1-day minimum**	**0.11**	**88**	**-0.224**	**-0.006**	**0.002**	**0.006**	**0.237**	**0.001**
16229000	**7-day minimum**	**0.14**	**88**	**-0.208**	**-0.007**	**0.004**	**0.010**	**0.226**	**0.002**
16229000	**30-day minimum**	**0.15**	**88**	**-0.196**	**-0.008**	**0.007**	**0.010**	**0.104**	**0.155**
16229000	1-day maximum	951	88	-0.122	-0.575	0.093	0.104	0.077	0.291
16229000	**7-day maximum**	**448**	**88**	**-0.189**	**-0.303**	**0.009**	**0.011**	**0.082**	**0.265**
16229000	**30-day maximum**	**292**	**88**	**-0.254**	**-0.162**	**0.000**	**0.001**	**0.140**	**0.056**
16400000	**Q_{90} (total flow)**	**4.8**	**77**	**-0.270**	**-0.027**	**0.001**	**0.002**	**0.209**	**0.009**
16400000	**Q_{75} (total flow)**	**7.6**	**77**	**-0.330**	**-0.040**	**0.000**	**0.000**	**0.248**	**0.002**
16400000	**Q_{50} (total flow)**	**13**	**77**	**-0.232**	**-0.045**	**0.003**	**0.005**	**0.111**	**0.158**
16400000	Q_{25} (total flow)	30	77	-0.083	-0.038	0.287	0.298	0.103	0.193
16400000	Q_{10} (total flow)	65	77	0.009	0.007	0.909	0.951	0.117	0.143
16400000	Mean (total flow)	29.6	77	-0.079	-0.033	0.310	0.328	0.140	0.079
16400000	**Q_{90} (base flow)**	**3.5**	**77**	**-0.287**	**-0.023**	**0.000**	**0.001**	**0.213**	**0.007**
16400000	**Q_{75} (base flow)**	**4.8**	**77**	**-0.374**	**-0.031**	**0.000**	**0.000**	**0.306**	**0.000**
16400000	**Q_{50} (base flow)**	**6.6**	**77**	**-0.431**	**-0.041**	**0.000**	**0.000**	**0.335**	**0.000**
16400000	**Q_{25} (base flow)**	**9.0**	**77**	**-0.443**	**-0.057**	**0.000**	**0.000**	**0.290**	**0.000**
16400000	**Q_{10} (base flow)**	**12**	**77**	**-0.403**	**-0.077**	**0.000**	**0.000**	**0.267**	**0.001**
16400000	**Mean (base flow)**	**7.38**	**77**	**-0.492**	**-0.051**	**0.000**	**0.000**	**0.439**	**0.000**
16400000	**1-day minimum**	**0.86**	**77**	**-0.195**	**-0.014**	**0.012**	**0.022**	**0.216**	**0.006**
16400000	**7-day minimum**	**0.90**	**77**	**-0.213**	**-0.017**	**0.006**	**0.013**	**0.201**	**0.012**
16400000	30-day minimum	0.99	77	-0.041	-0.007	0.604	0.543	0.015	0.852
16400000	1-day maximum	1240	77	0.055	0.594	0.479	0.627	0.258	0.001
16400000	7-day maximum	938	77	0.048	0.190	0.544	0.643	0.157	0.048
16400000	30-day maximum	726	77	-0.051	-0.077	0.512	0.472	0.086	0.279

Table 2. Results of Mann-Kendall test for trends in annual flows during 1913 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time				Relation between flow and previous year's flow	
				Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16508000	**Q_{90} (total flow)**	**2.8**	**80**	**-0.282**	**-0.017**	**0.000**	**0.000**	**0.140**	**0.068**
16508000	**Q_{75} (total flow)**	**4.0**	**80**	**-0.210**	**-0.020**	**0.006**	**0.009**	**0.138**	**0.073**
16508000	**Q_{50} (total flow)**	**7.0**	**80**	**-0.165**	**-0.025**	**0.030**	**0.038**	**0.121**	**0.114**
16508000	Q_{25} (total flow)	16	80	-0.013	0.000	0.865	0.866	0.048	0.530
16508000	Q_{10} (total flow)	50	80	0.132	0.177	0.084	0.099	0.050	0.517
16508000	Mean (total flow)	23.9	80	0.101	0.058	0.185	0.214	0.055	0.477
16508000	**Q_{90} (base flow)**	**2.5**	**80**	**-0.284**	**-0.015**	**0.000**	**0.000**	**0.121**	**0.115**
16508000	**Q_{75} (base flow)**	**3.3**	**80**	**-0.260**	**-0.017**	**0.001**	**0.001**	**0.128**	**0.097**
16508000	**Q_{50} (base flow)**	**4.6**	**80**	**-0.214**	**-0.020**	**0.005**	**0.010**	**0.174**	**0.023**
16508000	**Q_{25} (base flow)**	**6.9**	**80**	**-0.253**	**-0.030**	**0.001**	**0.003**	**0.176**	**0.022**
16508000	**Q_{10} (base flow)**	**9.7**	**80**	**-0.175**	**-0.032**	**0.022**	**0.023**	**-0.015**	**0.852**
16508000	**Mean (base flow)**	**5.61**	**80**	**-0.245**	**-0.023**	**0.001**	**0.003**	**0.120**	**0.117**
16508000	**1-day minimum**	**0.90**	**80**	**-0.362**	**-0.013**	**0.000**	**0.000**	**0.227**	**0.003**
16508000	**7-day minimum**	**0.95**	**80**	**-0.343**	**-0.015**	**0.000**	**0.000**	**0.200**	**0.009**
16508000	**30-day minimum**	**1.09**	**80**	**-0.228**	**-0.017**	**0.003**	**0.003**	**0.056**	**0.466**
16508000	1-day maximum	1610	80	0.121	1.994	0.112	0.146	0.124	0.106
16508000	7-day maximum	1210	80	0.060	0.327	0.430	0.411	0.052	0.498
16508000	30-day maximum	965	80	0.096	0.230	0.211	0.200	0.022	0.773
16587000	**Q_{90} (total flow)**	**0.73**	**90**	**-0.267**	**-0.005**	**0.000**	**0.001**	**0.251**	**0.001**
16587000	**Q_{75} (total flow)**	**1.2**	**90**	**-0.195**	**-0.006**	**0.006**	**0.009**	**0.092**	**0.202**
16587000	Q_{50} (total flow)	2.4	90	-0.144	-0.008	0.044	0.050	0.066	0.361
16587000	Q_{25} (total flow)	4.9	90	-0.064	-0.006	0.374	0.411	0.109	0.132
16587000	Q_{10} (total flow)	9.9	90	-0.043	-0.008	0.551	0.561	0.100	0.164
16587000	Mean (total flow)	4.80	90	-0.060	-0.006	0.407	0.422	0.112	0.120
16587000	**Q_{90} (base flow)**	**0.57**	**90**	**-0.277**	**-0.005**	**0.000**	**0.001**	**0.268**	**0.000**
16587000	**Q_{75} (base flow)**	**0.91**	**90**	**-0.225**	**-0.005**	**0.002**	**0.004**	**0.123**	**0.088**
16587000	**Q_{50} (base flow)**	**1.5**	**90**	**-0.166**	**-0.005**	**0.021**	**0.030**	**0.110**	**0.127**
16587000	**Q_{25} (base flow)**	**2.4**	**90**	**-0.168**	**-0.007**	**0.019**	**0.018**	**-0.001**	**0.997**
16587000	Q_{10} (base flow)	3.6	90	-0.114	-0.006	0.114	0.110	-0.042	0.559
16587000	**Mean (base flow)**	**1.86**	**90**	**-0.191**	**-0.006**	**0.008**	**0.011**	**0.069**	**0.340**
16587000	**1-day minimum**	**0.11**	**90**	**-0.267**	**-0.003**	**0.000**	**0.001**	**0.251**	**0.000**
16587000	**7-day minimum**	**0.11**	**90**	**-0.249**	**-0.004**	**0.001**	**0.002**	**0.229**	**0.002**
16587000	**30-day minimum**	**0.13**	**90**	**-0.200**	**-0.005**	**0.005**	**0.012**	**0.171**	**0.018**
16587000	1-day maximum	305	90	0.089	0.204	0.215	0.267	0.070	0.331
16587000	7-day maximum	264	90	-0.016	-0.012	0.821	0.822	0.056	0.442
16587000	30-day maximum	170	90	-0.006	-0.002	0.939	0.894	0.018	0.807

Table 2. Results of Mann-Kendall test for trends in annual flows during 1913 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time: Tau coefficient	Relation between flow and time: Slope, in cfs/yr	Relation between flow and time: 2p-value (ignoring serial correlation)[2]	Relation between flow and time: 2p-value (accounting for serial correlation)[3]	Relation between flow and previous year's flow: Tau coefficient	Relation between flow and previous year's flow: 2p-value
16620000	**Q_{90} (total flow)**	**13**	**84**	**-0.158**	**-0.034**	**0.033**	**0.048**	**0.211**	**0.005**
16620000	Q_{75} (total flow)	17	84	-0.153	-0.043	0.038	0.063	0.245	0.001
16620000	**Q_{50} (total flow)**	**24**	**84**	**-0.170**	**-0.063**	**0.022**	**0.045**	**0.280**	**0.000**
16620000	Q_{25} (total flow)	40	84	-0.133	-0.101	0.073	0.098	0.222	0.003
16620000	Q_{10} (total flow)	79	84	-0.096	-0.128	0.196	0.214	0.180	0.017
16620000	Mean (total flow)	39.1	84	-0.150	-0.088	0.044	0.064	0.224	0.003
16620000	**Q_{90} (base flow)**	**12**	**84**	**-0.159**	**-0.031**	**0.032**	**0.047**	**0.207**	**0.006**
16620000	**Q_{75} (base flow)**	**14**	**84**	**-0.183**	**-0.044**	**0.014**	**0.027**	**0.243**	**0.001**
16620000	**Q_{50} (base flow)**	**18**	**84**	**-0.174**	**-0.049**	**0.020**	**0.039**	**0.250**	**0.001**
16620000	**Q_{25} (base flow)**	**22**	**84**	**-0.189**	**-0.062**	**0.011**	**0.025**	**0.261**	**0.001**
16620000	**Q_{10} (base flow)**	**27**	**84**	**-0.171**	**-0.067**	**0.022**	**0.041**	**0.262**	**0.001**
16620000	**Mean (base flow)**	**19.1**	**84**	**-0.186**	**-0.050**	**0.012**	**0.030**	**0.296**	**0.000**
16620000	1-day minimum	8.50	84	-0.094	0.000	0.202	0.216	0.177	0.017
16620000	7-day minimum	8.50	84	-0.113	-0.022	0.130	0.157	0.238	0.002
16620000	30-day minimum	8.67	84	-0.102	-0.032	0.171	0.168	0.150	0.048
16620000	1-day maximum	781	84	-0.117	-1.030	0.115	0.130	0.083	0.274
16620000	7-day maximum	695	84	-0.133	-0.451	0.075	0.103	0.125	0.099
16620000	30-day maximum	588	84	-0.144	-0.224	0.053	0.073	0.115	0.128

[1]The Q_{pp} flow is the flow that is equaled or exceeded pp percent of the time.
[2]Attained significance level for the unmodified Mann-Kendall test.
[3]Attained significance level for the modified seasonal Mann-Kendall test.

Table 3. Results of Mann-Kendall test for trends in annual flows during 1933 to 2002 at long-term-trend stations, Hawaii.

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16068000	Q_{90} (total flow)	16	70	-0.091	-0.026	0.267	0.290	0.062	0.452
16068000	Q_{75} (total flow)	21	70	-0.092	-0.026	0.258	0.288	0.023	0.782
16068000	Q_{50} (total flow)	30	70	-0.066	-0.025	0.419	0.486	-0.078	0.341
16068000	Q_{25} (total flow)	47	70	-0.029	-0.022	0.722	0.818	-0.049	0.558
16068000	Q_{10} (total flow)	84	70	0.029	0.037	0.730	0.683	-0.003	0.975
16068000	Mean (total flow)	47.1	70	0.030	0.023	0.715	0.703	0.005	0.955
16068000	Q_{90} (base flow)	14	70	-0.106	-0.034	0.194	0.220	0.100	0.225
16068000	Q_{75} (base flow)	18	70	-0.095	-0.029	0.246	0.285	0.064	0.443
16068000	Q_{50} (base flow)	23	70	-0.075	-0.020	0.359	0.473	0.028	0.736
16068000	Q_{25} (base flow)	29	70	-0.053	-0.020	0.516	0.669	0.003	0.971
16068000	Q_{10} (base flow)	37	70	-0.040	-0.019	0.630	0.815	0.052	0.531
16068000	Mean (base flow)	24.6	70	-0.058	-0.018	0.484	0.593	0.020	0.816
16068000	1-day minimum	7.60	70	-0.124	-0.026	0.127	0.169	0.150	0.066
16068000	7-day minimum	7.97	70	-0.108	-0.027	0.187	0.212	0.096	0.246
16068000	30-day minimum	8.35	70	-0.123	-0.050	0.132	0.138	0.023	0.784
16068000	***1-day maximum***	***2570***	***70***	***0.187***	***5.684***	***0.022***	***0.037***	***0.075***	***0.365***
16068000	***7-day maximum***	***1690***	***70***	***0.199***	***1.863***	***0.015***	***0.027***	***0.111***	***0.180***
16068000	30-day maximum	1190	70	0.132	0.458	0.107	0.158	0.223	0.007
16200000	Q_{90} (total flow)	1.6	62	0.003	0.000	0.976	0.956	-0.057	0.523
16200000	Q_{75} (total flow)	3.2	62	0.008	0.000	0.932	0.906	0.004	0.969
16200000	Q_{50} (total flow)	6.6	62	-0.014	0.000	0.874	0.895	-0.046	0.605
16200000	Q_{25} (total flow)	15	62	0.005	0.000	0.956	1.000	-0.026	0.773
16200000	Q_{10} (total flow)	36	62	-0.019	-0.016	0.836	0.752	0.059	0.507
16200000	Mean (total flow)	15.6	62	-0.038	-0.011	0.671	0.624	0.041	0.651
16200000	Q_{90} (base flow)	0.87	62	0.004	0.000	0.966	0.916	-0.092	0.304
16200000	Q_{75} (base flow)	1.9	62	0.039	0.003	0.662	0.608	0.015	0.873
16200000	Q_{50} (base flow)	3.4	62	-0.020	-0.002	0.822	0.895	0.003	0.980
16200000	Q_{25} (base flow)	5.3	62	-0.106	-0.010	0.224	0.283	-0.064	0.475
16200000	**Q_{10} (base flow)**	**7.7**	**62**	**-0.200**	**-0.025**	**0.022**	**0.037**	**0.007**	**0.944**
16200000	Mean (base flow)	3.93	62	-0.097	-0.007	0.269	0.356	-0.006	0.954
16200000	1-day minimum	0.12	62	0.013	0.000	0.889	0.936	-0.052	0.561
16200000	7-day minimum	0.13	62	-0.026	-0.001	0.766	0.712	-0.083	0.352
16200000	30-day minimum	0.14	62	-0.003	0.000	0.981	0.995	-0.097	0.275
16200000	1-day maximum	975	62	-0.038	-0.364	0.666	0.585	0.127	0.153
16200000	7-day maximum	831	62	-0.108	-0.306	0.218	0.219	0.121	0.174
16200000	30-day maximum	524	62	-0.118	-0.093	0.178	0.155	0.044	0.623

Table 3. Results of Mann-Kendall test for trends in annual flows during 1933 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16229000	Q_{90} (total flow)	0.91	70	-0.143	-0.006	0.080	0.101	0.208	0.012
16229000	**Q_{75} (total flow)**	**1.5**	**70**	**-0.186**	**-0.009**	**0.023**	**0.035**	**0.160**	**0.051**
16229000	**Q_{50} (total flow)**	**2.6**	**70**	**-0.180**	**-0.013**	**0.028**	**0.034**	**0.104**	**0.205**
16229000	**Q_{25} (total flow)**	**5.1**	**70**	**-0.202**	**-0.029**	**0.014**	**0.021**	**0.137**	**0.097**
16229000	Q10 (total flow)	11	70	-0.161	-0.055	0.048	0.066	0.116	0.160
16229000	**Mean (total flow)**	**5.88**	**70**	**-0.183**	**-0.033**	**0.025**	**0.038**	**0.166**	**0.044**
16229000	**Q_{90} (base flow)**	**0.66**	**70**	**-0.180**	**-0.006**	**0.028**	**0.046**	**0.238**	**0.004**
16229000	**Q_{75} (base flow)**	**1.1**	**70**	**-0.184**	**-0.007**	**0.025**	**0.046**	**0.200**	**0.015**
16229000	**Q_{50} (base flow)**	**1.8**	**70**	**-0.216**	**-0.012**	**0.008**	**0.017**	**0.201**	**0.015**
16229000	**Q_{25} (base flow)**	**2.8**	**70**	**-0.247**	**-0.016**	**0.003**	**0.006**	**0.159**	**0.053**
16229000	**Q_{10} (base flow)**	**4.0**	**70**	**-0.253**	**-0.026**	**0.002**	**0.004**	**0.110**	**0.183**
16229000	**Mean (base flow)**	**2.13**	**70**	**-0.272**	**-0.015**	**0.001**	**0.003**	**0.200**	**0.015**
16229000	1-day minimum	0.11	70	-0.171	-0.005	0.037	0.075	0.347	0.000
16229000	7-day minimum	0.14	70	-0.147	-0.005	0.072	0.110	0.332	0.000
16229000	30-day minimum	0.17	70	-0.116	-0.005	0.159	0.176	0.164	0.047
16229000	1-day maximum	402	70	-0.162	-0.894	0.048	0.067	0.112	0.175
16229000	7-day maximum	303	70	-0.148	-0.273	0.071	0.080	0.067	0.419
16229000	**30-day maximum**	**232**	**70**	**-0.197**	**-0.134**	**0.016**	**0.028**	**0.134**	**0.105**
16400000	**Q_{90} (total flow)**	**4.6**	**64**	**-0.228**	**-0.029**	**0.008**	**0.017**	**0.205**	**0.018**
16400000	**Q_{75} (total flow)**	**7.2**	**64**	**-0.265**	**-0.042**	**0.002**	**0.007**	**0.233**	**0.007**
16400000	**Q_{50} (total flow)**	**13**	**64**	**-0.203**	**-0.051**	**0.017**	**0.027**	**0.135**	**0.113**
16400000	Q_{25} (total flow)	29	64	-0.032	-0.012	0.710	0.701	0.152	0.080
16400000	Q_{10} (total flow)	65	64	-0.010	-0.009	0.908	0.875	0.148	0.087
16400000	Mean (total flow)	29.6	64	-0.109	-0.062	0.205	0.241	0.196	0.023
16400000	**Q_{90} (base flow)**	**3.3**	**64**	**-0.197**	**-0.020**	**0.021**	**0.034**	**0.186**	**0.032**
16400000	**Q_{75} (base flow)**	**4.6**	**64**	**-0.244**	**-0.026**	**0.004**	**0.013**	**0.235**	**0.007**
16400000	**Q_{50} (base flow)**	**6.3**	**64**	**-0.305**	**-0.035**	**0.000**	**0.002**	**0.262**	**0.002**
16400000	**Q_{25} (base flow)**	**8.6**	**64**	**-0.371**	**-0.060**	**0.000**	**0.000**	**0.259**	**0.003**
16400000	**Q_{10} (base flow)**	**11**	**64**	**-0.316**	**-0.071**	**0.000**	**0.001**	**0.238**	**0.006**
16400000	**Mean (base flow)**	**6.91**	**64**	**-0.371**	**-0.044**	**0.000**	**0.000**	**0.367**	**0.000**
16400000	1-day minimum	0.86	64	-0.101	-0.008	0.241	0.267	0.225	0.009
16400000	7-day minimum	0.90	64	-0.137	-0.013	0.110	0.141	0.199	0.021
16400000	30-day minimum	1.00	64	-0.030	-0.007	0.728	0.665	0.055	0.530
16400000	1-day maximum	1240	64	-0.119	-1.646	0.166	0.173	0.212	0.014
16400000	7-day maximum	938	64	0.076	0.355	0.379	0.500	0.210	0.015
16400000	30-day maximum	725	64	-0.061	-0.094	0.483	0.450	0.119	0.169

Table 3. Results of Mann-Kendall test for trends in annual flows during 1933 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16508000	**Q_{90} (total flow)**	**2.7**	**70**	**-0.193**	**-0.011**	**0.018**	**0.017**	**0.084**	**0.309**
16508000	Q_{75} (total flow)	3.9	70	-0.117	-0.011	0.153	0.135	0.118	0.152
16508000	Q_{50} (total flow)	6.8	70	-0.094	-0.013	0.249	0.217	0.138	0.095
16508000	Q_{25} (total flow)	16	70	-0.026	0.000	0.757	0.686	0.053	0.523
16508000	Q_{10} (total flow)	52	70	0.072	0.115	0.383	0.498	0.044	0.597
16508000	Mean (total flow)	24.5	70	0.058	0.032	0.478	0.622	0.061	0.465
16508000	**Q_{90} (base flow)**	**2.4**	**70**	**-0.185**	**-0.010**	**0.024**	**0.019**	**0.045**	**0.586**
16508000	**Q_{75} (base flow)**	**3.1**	**70**	**-0.158**	**-0.009**	**0.054**	**0.045**	**0.068**	**0.410**
16508000	Q_{50} (base flow)	4.4	70	-0.113	-0.011	0.169	0.165	0.150	0.070
16508000	Q25 (base flow)	6.6	70	-0.167	-0.020	0.042	0.059	0.130	0.117
16508000	Q_{10} (base flow)	9.3	70	-0.116	-0.022	0.156	0.161	-0.030	0.721
16508000	Mean (base flow)	5.40	70	-0.151	-0.014	0.065	0.067	0.089	0.284
16508000	**1-day minimum**	**0.90**	**70**	**-0.253**	**-0.010**	**0.002**	**0.003**	**0.121**	**0.139**
16508000	**7-day minimum**	**0.95**	**70**	**-0.241**	**-0.011**	**0.003**	**0.005**	**0.105**	**0.202**
16508000	**30-day minimum**	**1.09**	**70**	**-0.174**	**-0.014**	**0.034**	**0.025**	**0.038**	**0.652**
16508000	1-day maximum	1610	70	-0.006	-0.086	0.947	0.934	0.074	0.370
16508000	7-day maximum	1210	70	-0.004	-0.039	0.964	0.939	0.019	0.824
16508000	30-day maximum	964	70	0.000	-0.002	1.000	0.941	-0.017	0.840
16587000	**Q_{90} (total flow)**	**0.65**	**70**	**-0.165**	**-0.004**	**0.043**	**0.041**	**0.223**	**0.007**
16587000	Q_{75} (total flow)	1.2	70	-0.089	-0.003	0.275	0.203	0.091	0.270
16587000	Q_{50} (total flow)	2.3	70	-0.053	-0.003	0.519	0.401	0.078	0.342
16587000	Q_{25} (total flow)	4.7	70	0.014	0.001	0.867	0.993	0.168	0.042
16587000	Q_{10} (total flow)	9.6	70	0.007	0.000	0.931	0.961	0.177	0.031
16587000	Mean (total flow)	4.64	70	0.048	0.006	0.563	0.716	0.183	0.026
16587000	**Q_{90} (base flow)**	**0.52**	**70**	**-0.163**	**-0.003**	**0.046**	**0.048**	**0.225**	**0.006**
16587000	Q_{75} (base flow)	0.84	70	-0.104	-0.003	0.207	0.162	0.086	0.298
16587000	Q_{50} (base flow)	1.4	70	-0.031	-0.001	0.711	0.573	0.100	0.227
16587000	Q_{25} (base flow)	2.3	70	-0.063	-0.002	0.441	0.356	0.006	0.950
16587000	Q_{10} (base flow)	3.3	70	-0.029	-0.002	0.730	0.616	-0.080	0.333
16587000	Mean (base flow)	1.75	70	-0.070	-0.003	0.394	0.306	0.045	0.587
16587000	**1-day minimum**	**0.11**	**70**	**-0.179**	**-0.003**	**0.029**	**0.027**	**0.192**	**0.019**
16587000	**7-day minimum**	**0.11**	**70**	**-0.183**	**-0.003**	**0.025**	**0.025**	**0.224**	**0.007**
16587000	**30-day minimum**	**0.13**	**70**	**-0.166**	**-0.005**	**0.042**	**0.036**	**0.165**	**0.046**
16587000	1-day maximum	305	70	0.168	0.576	0.040	0.070	0.093	0.261
16587000	7-day maximum	264	70	0.083	0.107	0.313	0.335	0.065	0.434
16587000	30-day maximum	164	70	0.083	0.040	0.311	0.380	0.047	0.572

Table 3. Results of Mann-Kendall test for trends in annual flows during 1933 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time				Relation between flow and previous year's flow	
				Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16620000	Q_{90} (total flow)	13	68	-0.043	0.000	0.609	0.580	0.182	0.029
16620000	Q_{75} (total flow)	17	68	-0.011	0.000	0.903	0.862	0.192	0.022
16620000	Q_{50} (total flow)	23	68	-0.017	0.000	0.840	0.775	0.239	0.004
16620000	Q_{25} (total flow)	39	68	-0.030	-0.023	0.719	0.611	0.217	0.010
16620000	Q_{10} (total flow)	77	68	-0.066	-0.106	0.430	0.357	0.184	0.030
16620000	Mean (total flow)	37.8	68	-0.049	-0.032	0.557	0.488	0.219	0.010
16620000	Q_{90} (base flow)	12	68	-0.032	0.000	0.698	0.647	0.179	0.033
16620000	Q_{75} (base flow)	14	68	-0.036	-0.007	0.668	0.638	0.193	0.022
16620000	Q_{50} (base flow)	17	68	0.005	0.000	0.958	0.992	0.183	0.030
16620000	Q_{25} (base flow)	21	68	-0.014	-0.003	0.874	0.786	0.192	0.023
16620000	Q_{10} (base flow)	26	68	0.009	0.001	0.916	0.953	0.204	0.016
16620000	Mean (base flow)	18.2	68	-0.024	-0.006	0.779	0.731	0.225	0.008
16620000	1-day minimum	8.50	68	-0.007	0.000	0.932	0.879	0.173	0.036
16620000	7-day minimum	8.50	68	-0.020	-0.004	0.816	0.759	0.230	0.006
16620000	30-day minimum	8.67	68	-0.034	-0.011	0.684	0.601	0.112	0.184
16620000	1-day maximum	781	68	-0.012	-0.100	0.886	0.919	0.017	0.842
16620000	7-day maximum	695	68	-0.082	-0.297	0.327	0.386	0.059	0.489
16620000	30-day maximum	564	68	-0.104	-0.182	0.212	0.219	0.076	0.367

[1]The Q_{pp} flow is the flow that is equaled or exceeded pp percent of the time.

[2]Attained significance level for the unmodified Mann-Kendall test.

[3]Attained significance level for the modified seasonal Mann-Kendall test.

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16019000	Q_{90} (total flow)	2.6	50	-0.035	0.000	0.724	0.529	-0.023	0.821
16019000	Q_{75} (total flow)	3.7	50	-0.104	-0.008	0.287	0.172	-0.059	0.556
16019000	Q_{50} (total flow)	6.6	50	-0.113	-0.014	0.251	0.144	-0.145	0.145
16019000	Q_{25} (total flow)	15	50	-0.017	0.000	0.867	0.747	-0.168	0.088
16019000	Q_{10} (total flow)	45	50	-0.107	-0.167	0.277	0.155	-0.136	0.170
16019000	Mean (total flow)	21.5	50	-0.133	-0.073	0.175	0.094	-0.088	0.375
16019000	Q_{90} (base flow)	2.2	50	0.120	0.004	0.222	0.309	-0.009	0.938
16019000	Q_{75} (base flow)	2.7	50	0.005	0.000	0.967	0.896	0.080	0.422
16019000	Q_{50} (base flow)	3.5	50	-0.101	-0.006	0.303	0.226	0.020	0.843
16019000	Q_{25} (base flow)	4.9	50	-0.121	-0.012	0.219	0.201	0.081	0.418
16019000	Q_{10} (base flow)	6.9	50	-0.104	-0.018	0.292	0.211	0.010	0.924
16019000	Mean (base flow)	4.14	50	-0.107	-0.008	0.277	0.190	-0.019	0.856
16019000	1-day minimum	0.99	50	0.204	0.008	0.036	0.069	0.116	0.240
16019000	7-day minimum	1.04	50	0.170	0.007	0.083	0.109	-0.005	0.966
16019000	30-day minimum	1.17	50	-0.033	-0.004	0.744	0.555	-0.170	0.086
16019000	1-day maximum	1440	50	-0.090	-2.048	0.362	0.309	0.131	0.187
16019000	7-day maximum	966	50	-0.064	-0.584	0.514	0.443	0.061	0.541
16019000	30-day maximum	718	50	-0.141	-0.488	0.150	0.123	0.066	0.507
16068000	Q_{90} (total flow)	15	50	0.024	0.000	0.814	0.984	0.082	0.404
16068000	Q_{75} (total flow)	20	50	-0.009	0.000	0.933	0.771	0.071	0.470
16068000	Q_{50} (total flow)	30	50	-0.054	-0.026	0.586	0.446	-0.069	0.488
16068000	Q_{25} (total flow)	47	50	-0.082	-0.091	0.403	0.286	-0.060	0.551
16068000	Q_{10} (total flow)	85	50	-0.070	-0.183	0.477	0.354	-0.019	0.856
16068000	Mean (total flow)	48.1	50	-0.068	-0.101	0.493	0.335	-0.014	0.897
16068000	Q_{90} (base flow)	14	50	0.049	0.016	0.621	0.781	0.116	0.244
16068000	Q_{75} (base flow)	17	50	0.051	0.023	0.604	0.779	0.105	0.289
16068000	Q_{50} (base flow)	23	50	-0.016	-0.007	0.880	0.796	0.054	0.587
16068000	Q_{25} (base flow)	29	50	-0.072	-0.041	0.467	0.412	0.003	0.979
16068000	Q_{10} (base flow)	37	50	-0.131	-0.085	0.181	0.166	0.002	0.993
16068000	Mean (base flow)	24.4	50	-0.053	-0.020	0.592	0.506	0.046	0.648
16068000	1-day minimum	7.60	50	0.078	0.011	0.429	0.585	0.166	0.091
16068000	7-day minimum	7.97	50	0.045	0.020	0.651	0.836	0.105	0.289
16068000	30-day minimum	8.35	50	0.008	0.004	0.940	0.869	0.044	0.660
16068000	1-day maximum	2570	50	-0.013	-0.925	0.900	0.685	-0.037	0.711
16068000	7-day maximum	1690	50	-0.020	-0.189	0.841	0.702	0.049	0.623
16068000	30-day maximum	1180	50	-0.076	-0.371	0.442	0.421	0.158	0.111

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16097500	Q_{90} (total flow)	4.6	44	0.050	0.004	0.641	0.708	0.209	0.048
16097500	Q_{75} (total flow)	5.6	44	-0.004	0.000	0.976	0.957	0.199	0.061
16097500	Q_{50} (total flow)	7.4	44	-0.107	-0.012	0.311	0.404	0.245	0.021
16097500	Q_{25} (total flow)	11	44	-0.206	-0.048	0.048	0.075	0.104	0.325
16097500	Q_{10} (total flow)	20	44	-0.116	-0.065	0.270	0.349	0.118	0.266
16097500	Mean (total flow)	11.8	44	-0.072	-0.023	0.498	0.520	0.079	0.464
16097500	Q_{90} (base flow)	4.3	44	0.087	0.008	0.412	0.507	0.231	0.029
16097500	Q_{75} (base flow)	5.1	44	0.039	0.004	0.716	0.759	0.181	0.090
16097500	Q_{50} (base flow)	6.1	44	-0.015	-0.002	0.895	0.920	0.285	0.007
16097500	Q_{25} (base flow)	7.3	44	-0.130	-0.014	0.217	0.359	0.344	0.001
16097500	Q10 (base flow)	8.8	44	-0.226	-0.029	0.031	0.086	0.243	0.023
16097500	Mean (base flow)	6.38	44	-0.076	-0.008	0.473	0.568	0.274	0.010
16097500	1-day minimum	1.90	44	0.184	0.013	0.079	0.166	0.383	0.000
16097500	7-day minimum	2.01	44	0.165	0.012	0.117	0.205	0.323	0.002
16097500	30-day minimum	2.45	44	0.093	0.009	0.379	0.450	0.141	0.187
16097500	1-day maximum	879	44	0.091	1.171	0.390	0.401	0.096	0.368
16097500	7-day maximum	475	44	0.110	0.369	0.298	0.295	0.030	0.786
16097500	30-day maximum	285	44	0.017	0.030	0.879	0.821	0.110	0.305
16108000	Q_{90} (total flow)	49	47	0.049	0.015	0.632	0.689	0.141	0.171
16108000	Q_{75} (total flow)	58	47	0.038	0.025	0.713	0.785	0.079	0.450
16108000	Q_{50} (total flow)	79	47	-0.012	0.000	0.912	0.800	0.003	0.984
16108000	Q_{25} (total flow)	136	47	-0.014	-0.036	0.898	0.838	-0.095	0.363
16108000	Q_{10} (total flow)	261	47	-0.060	-0.375	0.557	0.392	-0.053	0.618
16108000	Mean (total flow)	138	47	-0.068	-0.179	0.509	0.431	0.085	0.417
16108000	Q_{90} (base flow)	44	47	0.093	0.065	0.364	0.457	0.203	0.050
16108000	Q_{75} (base flow)	49	47	0.056	0.045	0.588	0.661	0.176	0.091
16108000	Q_{50} (base flow)	56	47	0.061	0.037	0.551	0.603	0.103	0.323
16108000	Q_{25} (base flow)	64	47	0.023	0.018	0.826	0.854	-0.022	0.837
16108000	Q_{10} (base flow)	75	47	0.003	0.002	0.985	1.000	0.077	0.463
16108000	Mean (base flow)	58.4	47	0.064	0.042	0.533	0.567	0.121	0.244
16108000	1-day minimum	32.0	47	0.072	0.036	0.478	0.575	0.240	0.020
16108000	7-day minimum	32.9	47	0.097	0.068	0.340	0.448	0.249	0.016
16108000	30-day minimum	34.1	47	0.005	0.009	0.971	0.895	0.115	0.269
16108000	1-day maximum	3650	47	0.016	1.111	0.883	0.959	0.141	0.174
16108000	7-day maximum	2910	47	0.037	1.300	0.721	0.796	0.093	0.373
16108000	30-day maximum	2360	47	-0.045	-0.521	0.660	0.606	0.117	0.261

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time				Relation between flow and previous year's flow	
				Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16200000	Q_{90} (total flow)	1.6	42	0.021	0.001	0.854	0.967	-0.085	0.437
16200000	Q_{75} (total flow)	3.2	42	0.049	0.006	0.657	0.740	0.018	0.875
16200000	Q_{50} (total flow)	6.5	42	-0.021	-0.001	0.854	0.855	-0.094	0.392
16200000	Q_{25} (total flow)	15	42	-0.039	0.000	0.720	0.734	-0.094	0.390
16200000	Q_{10} (total flow)	36	42	-0.099	-0.129	0.362	0.324	-0.002	0.991
16200000	Mean (total flow)	15.8	42	-0.134	-0.072	0.217	0.184	0.005	0.973
16200000	Q_{90} (base flow)	0.93	42	0.015	0.001	0.897	0.986	-0.105	0.340
16200000	Q_{75} (base flow)	1.9	42	0.062	0.008	0.573	0.616	0.032	0.779
16200000	Q_{50} (base flow)	3.4	42	-0.016	-0.002	0.888	0.866	0.028	0.805
16200000	Q_{25} (base flow)	5.1	42	0.005	0.000	0.974	0.884	-0.118	0.281
16200000	Q_{10} (base flow)	7.4	42	-0.110	-0.014	0.308	0.381	-0.032	0.779
16200000	Mean (base flow)	3.84	42	-0.027	-0.004	0.812	0.859	-0.054	0.629
16200000	1-day minimum	0.13	42	0.013	0.001	0.914	0.995	-0.144	0.188
16200000	7-day minimum	0.13	42	-0.038	-0.002	0.729	0.618	-0.130	0.234
16200000	30-day minimum	0.15	42	-0.036	-0.007	0.745	0.647	-0.193	0.078
16200000	**1-day maximum**	**970**	**42**	**-0.238**	**-5.000**	**0.027**	**0.028**	**0.127**	**0.247**
16200000	7-day maximum	787	42	-0.206	-1.114	0.056	0.052	0.093	0.400
16200000	**30-day maximum**	**477**	**42**	**-0.226**	**-0.431**	**0.036**	**0.030**	**0.027**	**0.814**
16211600	Q_{90} (total flow)	0.00	43	-0.205	-0.001	0.050	0.150	0.434	0.000
16211600	Q_{75} (total flow)	0.15	43	-0.136	-0.003	0.201	0.358	0.322	0.003
16211600	Q_{50} (total flow)	0.50	43	-0.167	-0.008	0.116	0.230	0.239	0.026
16211600	Q_{25} (total flow)	1.4	43	-0.250	-0.026	0.018	0.052	0.192	0.075
16211600	**Q_{10} (total flow)**	**3.3**	**43**	**-0.331**	**-0.076**	**0.002**	**0.008**	**0.196**	**0.069**
16211600	**Mean (total flow)**	**1.73**	**43**	**-0.289**	**-0.034**	**0.007**	**0.019**	**0.154**	**0.153**
16211600	Q_{90} (base flow)	0.00	43	-0.221	-0.001	0.034	0.117	0.437	0.000
16211600	Q_{75} (base flow)	0.08	43	-0.193	-0.002	0.069	0.192	0.426	0.000
16211600	Q_{50} (base flow)	0.29	43	-0.142	-0.005	0.183	0.341	0.330	0.002
16211600	**Q_{25} (base flow)**	**0.70**	**43**	**-0.257**	**-0.015**	**0.016**	**0.049**	**0.250**	**0.020**
16211600	**Q_{10} (base flow)**	**1.3**	**43**	**-0.307**	**-0.027**	**0.004**	**0.019**	**0.237**	**0.028**
16211600	Mean (base flow)	0.51	43	-0.238	-0.010	0.025	0.076	0.257	0.017
16211600	1-day minimum	0.00	43	-0.101	0.000	0.314	0.470	0.334	0.000
16211600	7-day minimum	0.00	43	-0.177	0.000	0.085	0.200	0.362	0.000
16211600	30-day minimum	0.00	43	-0.221	-0.002	0.036	0.122	0.412	0.000
16211600	1-day maximum	283	43	-0.123	-0.484	0.250	0.209	-0.016	0.888
16211600	7-day maximum	175	43	-0.173	-0.257	0.105	0.099	0.031	0.778
16211600	**30-day maximum**	**109**	**43**	**-0.282**	**-0.160**	**0.008**	**0.013**	**0.087**	**0.423**

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.—Continued

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				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16226000	***Q_{90} (total flow)***	***0.00***	***49***	***0.160***	***0.000***	***0.027***	***0.022***	***0.004***	***0.961***
16226000	***Q_{75} (total flow)***	***0.01***	***49***	***0.192***	***0.000***	***0.035***	***0.032***	***0.055***	***0.526***
16226000	Q_{50} (total flow)	0.33	49	0.045	0.001	0.654	0.612	-0.066	0.516
16226000	Q_{25} (total flow)	2.5	49	-0.064	-0.011	0.524	0.536	-0.064	0.528
16226000	Q_{10} (total flow)	10	49	-0.105	-0.060	0.289	0.320	0.007	0.950
16226000	Mean (total flow)	4.82	49	-0.150	-0.037	0.131	0.149	0.094	0.351
16226000	***Q_{90} (base flow)***	***0.00***	***49***	***0.169***	***0.000***	***0.015***	***0.015***	***0.023***	***0.657***
16226000	Q_{75} (base flow)	0.00	49	0.153	0.000	0.068	0.070	0.063	0.392
16226000	Q_{50} (base flow)	0.03	49	-0.034	0.000	0.735	0.809	-0.082	0.406
16226000	Q_{25} (base flow)	0.19	49	-0.108	-0.002	0.277	0.256	-0.079	0.433
16226000	**Q_{10} (base flow)**	**0.71**	**49**	**-0.192**	**-0.009**	**0.052**	**0.048**	**-0.063**	**0.534**
16226000	Mean (base flow)	0.25	49	-0.157	-0.002	0.113	0.102	-0.059	0.557
16226000	1-day minimum	0.00	49	0.068	0.000	0.100	0.079	-0.008	0.685
16226000	***7-day minimum***	***0.00***	***49***	***0.115***	***0.000***	***0.027***	***0.047***	***0.059***	***0.039***
16226000	***30-day minimum***	***0.00***	***49***	***0.261***	***0.000***	***0.005***	***0.008***	***0.062***	***0.478***
16226000	**1-day maximum**	**514**	**49**	**-0.313**	**-3.233**	**0.002**	**0.003**	**0.167**	**0.096**
16226000	**7-day maximum**	**406**	**49**	**-0.286**	**-0.916**	**0.004**	**0.009**	**0.193**	**0.054**
16226000	**30-day maximum**	**292**	**49**	**-0.284**	**-0.313**	**0.004**	**0.010**	**0.176**	**0.080**
16229000	Q_{90} (total flow)	0.82	50	0.078	0.003	0.426	0.594	0.123	0.213
16229000	Q_{75} (total flow)	1.4	50	-0.010	0.000	0.927	0.822	0.067	0.500
16229000	Q_{50} (total flow)	2.4	50	-0.042	-0.002	0.675	0.610	-0.021	0.835
16229000	Q_{25} (total flow)	4.8	50	-0.140	-0.023	0.155	0.139	0.038	0.704
16229000	Q_{10} (total flow)	10	50	-0.109	-0.040	0.269	0.236	0.044	0.660
16229000	Mean (total flow)	5.57	50	-0.125	-0.027	0.204	0.156	0.104	0.297
16229000	Q_{90} (base flow)	0.59	50	0.062	0.003	0.530	0.688	0.141	0.155
16229000	Q_{75} (base flow)	1.0	50	0.017	0.001	0.867	0.987	0.109	0.273
16229000	Q_{50} (base flow)	1.6	50	-0.020	-0.001	0.841	0.761	0.068	0.496
16229000	Q_{25} (base flow)	2.5	50	-0.117	-0.009	0.235	0.223	0.041	0.685
16229000	**Q_{10} (base flow)**	**3.7**	**50**	**-0.235**	**-0.033**	**0.016**	**0.022**	**0.022**	**0.829**
16229000	Mean (base flow)	1.97	50	-0.154	-0.011	0.116	0.124	0.095	0.339
16229000	1-day minimum	0.11	50	0.104	0.004	0.291	0.481	0.317	0.001
16229000	7-day minimum	0.14	50	0.122	0.005	0.213	0.383	0.310	0.002
16229000	30-day minimum	0.17	50	0.086	0.006	0.384	0.545	0.128	0.199
16229000	**1-day maximum**	**327**	**50**	**-0.190**	**-1.500**	**0.052**	**0.046**	**0.149**	**0.134**
16229000	**7-day maximum**	**267**	**50**	**-0.196**	**-0.437**	**0.046**	**0.038**	**0.126**	**0.205**
16229000	**30-day maximum**	**207**	**50**	**-0.203**	**-0.180**	**0.038**	**0.040**	**0.165**	**0.096**

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time				Relation between flow and previous year's flow	
				Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16303003	Q_{90} (total flow)	13	49	-0.095	-0.027	0.339	0.424	0.327	0.001
16303003	Q_{75} (total flow)	16	49	-0.116	-0.033	0.244	0.304	0.274	0.006
16303003	Q_{50} (total flow)	19	49	-0.179	-0.071	0.070	0.125	0.270	0.007
16303003	Q_{25} (total flow)	25	49	-0.168	-0.095	0.091	0.136	0.193	0.054
16303003	Q_{10} (total flow)	35	49	-0.095	-0.096	0.339	0.343	0.117	0.244
16303003	Mean (total flow)	24.8	49	-0.133	-0.081	0.182	0.206	0.191	0.056
16303003	Q_{90} (base flow)	13	49	-0.072	-0.021	0.469	0.547	0.330	0.001
16303003	Q_{75} (base flow)	15	49	-0.141	-0.037	0.155	0.239	0.336	0.001
16303003	Q_{50} (base flow)	18	49	-0.196	-0.080	0.048	0.095	0.312	0.002
16303003	**Q_{25} (base flow)**	**21**	**49**	**-0.238**	**-0.088**	**0.016**	**0.042**	**0.270**	**0.007**
16303003	Q_{10} (base flow)	24	49	-0.209	-0.094	0.035	0.073	0.328	0.001
16303003	Mean (base flow)	18.2	49	-0.192	-0.065	0.052	0.109	0.348	0.001
16303003	1-day minimum	7.98	49	-0.082	-0.025	0.413	0.450	0.197	0.049
16303003	7-day minimum	8.52	49	-0.071	-0.016	0.474	0.555	0.310	0.002
16303003	30-day minimum	9.00	49	-0.068	-0.023	0.496	0.557	0.236	0.019
16303003	1-day maximum	1020	49	-0.104	-1.463	0.297	0.188	-0.057	0.576
16303003	7-day maximum	678	49	-0.084	-0.403	0.398	0.311	0.055	0.588
16303003	30-day maximum	432	49	-0.163	-0.238	0.100	0.106	0.167	0.097
16400000	Q_{90} (total flow)	4.4	50	-0.153	-0.024	0.118	0.154	0.209	0.035
16400000	Q_{75} (total flow)	7.0	50	-0.185	-0.035	0.059	0.089	0.189	0.057
16400000	Q_{50} (total flow)	13	50	-0.164	-0.054	0.092	0.105	0.074	0.452
16400000	Q_{25} (total flow)	29	50	-0.007	0.000	0.953	0.851	0.116	0.244
16400000	Q_{10} (total flow)	65	50	0.033	0.056	0.738	0.898	0.121	0.224
16400000	Mean (total flow)	29.3	50	-0.073	-0.054	0.462	0.447	0.190	0.055
16400000	Q_{90} (base flow)	3.2	50	-0.142	-0.019	0.148	0.195	0.180	0.069
16400000	Q_{75} (base flow)	4.4	50	-0.190	-0.027	0.052	0.106	0.196	0.048
16400000	**Q_{50} (base flow)**	**6.1**	**50**	**-0.266**	**-0.037**	**0.007**	**0.024**	**0.213**	**0.032**
16400000	**Q_{25} (base flow)**	**8.2**	**50**	**-0.321**	**-0.061**	**0.001**	**0.004**	**0.177**	**0.074**
16400000	**Q_{10} (base flow)**	**11**	**50**	**-0.291**	**-0.080**	**0.003**	**0.008**	**0.168**	**0.091**
16400000	**Mean (base flow)**	**6.63**	**50**	**-0.322**	**-0.047**	**0.001**	**0.006**	**0.304**	**0.002**
16400000	1-day minimum	0.86	50	0.054	0.004	0.586	0.663	0.274	0.005
16400000	7-day minimum	0.90	50	-0.034	-0.005	0.732	0.752	0.226	0.022
16400000	30-day minimum	1.00	50	0.088	0.027	0.371	0.482	0.085	0.393
16400000	1-day maximum	1240	50	-0.131	-2.522	0.183	0.208	0.248	0.012
16400000	7-day maximum	937	50	0.069	0.388	0.482	0.651	0.293	0.003
16400000	30-day maximum	690	50	-0.035	-0.071	0.725	0.639	0.196	0.048

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test;
bold italic blue type indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test;
cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16508000	Q_{90} (total flow)	2.6	50	-0.061	-0.004	0.535	0.405	0.031	0.762
16508000	Q_{75} (total flow)	3.7	50	-0.013	0.000	0.900	0.741	0.148	0.135
16508000	Q_{50} (total flow)	6.5	50	0.029	0.004	0.769	0.971	0.110	0.269
16508000	Q_{25} (total flow)	15	50	0.021	0.000	0.834	0.946	0.009	0.931
16508000	Q_{10} (total flow)	55	50	-0.002	0.000	0.987	0.880	0.006	0.959
16508000	Mean (total flow)	25.1	50	-0.006	-0.005	0.960	0.794	0.034	0.737
16508000	Q_{90} (base flow)	2.4	50	-0.053	-0.003	0.592	0.476	-0.020	0.843
16508000	Q_{75} (base flow)	3.0	50	-0.077	-0.005	0.436	0.373	0.080	0.422
16508000	Q_{50} (base flow)	4.2	50	0.051	0.004	0.610	0.780	0.140	0.157
16508000	Q_{25} (base flow)	6.2	50	0.035	0.007	0.725	0.892	0.019	0.856
16508000	Q_{10} (base flow)	8.8	50	0.038	0.010	0.700	0.665	-0.099	0.322
16508000	Mean (base flow)	5.13	50	0.015	0.002	0.887	0.973	0.027	0.789
16508000	1-day minimum	0.90	50	-0.091	-0.003	0.351	0.301	0.027	0.788
16508000	7-day minimum	0.95	50	-0.083	-0.004	0.398	0.331	0.023	0.823
16508000	30-day minimum	1.09	50	-0.060	-0.006	0.541	0.375	-0.034	0.737
16508000	1-day maximum	1170	50	-0.007	-0.086	0.953	0.821	0.059	0.558
16508000	7-day maximum	1080	50	-0.020	-0.115	0.847	0.771	0.012	0.911
16508000	30-day maximum	882	50	-0.061	-0.238	0.536	0.451	-0.053	0.599
16587000	Q_{90} (total flow)	0.63	50	0.007	0.000	0.953	0.924	0.135	0.172
16587000	Q_{75} (total flow)	1.1	50	-0.036	-0.001	0.719	0.585	0.083	0.401
16587000	Q_{50} (total flow)	2.2	50	0.002	0.000	0.987	0.828	0.043	0.672
16587000	Q_{25} (total flow)	4.6	50	0.065	0.009	0.509	0.649	0.172	0.083
16587000	Q_{10} (total flow)	9.5	50	0.060	0.018	0.541	0.632	0.141	0.154
16587000	Mean (total flow)	4.67	50	0.091	0.013	0.358	0.475	0.175	0.077
16587000	Q_{90} (base flow)	0.48	50	0.024	0.001	0.808	0.945	0.099	0.317
16587000	Q_{75} (base flow)	0.81	50	-0.025	-0.001	0.802	0.680	0.067	0.501
16587000	Q_{50} (base flow)	1.4	50	-0.002	0.000	0.993	0.817	0.063	0.529
16587000	Q_{25} (base flow)	2.2	50	0.000	0.000	1.000	0.839	-0.019	0.856
16587000	Q_{10} (base flow)	3.3	50	0.053	0.005	0.592	0.599	-0.140	0.157
16587000	Mean (base flow)	1.71	50	0.007	0.000	0.953	0.904	-0.003	0.979
16587000	1-day minimum	0.11	50	0.023	0.000	0.821	0.912	0.032	0.749
16587000	7-day minimum	0.11	50	0.034	0.001	0.732	0.850	0.062	0.535
16587000	30-day minimum	0.13	50	0.039	0.001	0.694	0.852	0.017	0.870
16587000	1-day maximum	305	50	0.144	0.636	0.143	0.185	0.056	0.575
16587000	7-day maximum	264	50	0.100	0.196	0.311	0.332	0.041	0.685
16587000	30-day maximum	158	50	0.125	0.082	0.204	0.226	0.020	0.843

Table 4. Results of Mann-Kendall test for trends in annual flows during 1953 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16618000	Q_{90} (total flow)	5.1	45	-0.032	-0.004	0.762	0.749	0.164	0.123
16618000	Q_{75} (total flow)	6.3	45	-0.052	-0.005	0.624	0.621	0.144	0.176
16618000	Q_{50} (total flow)	8.8	45	-0.041	-0.004	0.695	0.652	0.134	0.207
16618000	Q_{25} (total flow)	16	45	0.019	0.000	0.860	0.937	0.128	0.225
16618000	Q_{10} (total flow)	35	45	0.111	0.094	0.286	0.419	0.100	0.351
16618000	Mean (total flow)	17.6	45	0.083	0.031	0.428	0.596	0.127	0.233
16618000	Q_{90} (base flow)	4.6	45	-0.044	-0.004	0.674	0.674	0.173	0.105
16618000	Q_{75} (base flow)	5.3	45	-0.043	-0.006	0.681	0.663	0.118	0.267
16618000	Q_{50} (base flow)	6.3	45	-0.090	-0.013	0.389	0.396	0.074	0.490
16618000	Q_{25} (base flow)	7.8	45	-0.114	-0.018	0.273	0.330	0.174	0.103
16618000	Q_{10} (base flow)	9.4	45	-0.138	-0.023	0.183	0.260	0.218	0.040
16618000	Mean (base flow)	6.72	45	-0.115	-0.014	0.269	0.314	0.174	0.103
16618000	1-day minimum	2.70	45	-0.019	0.000	0.860	0.759	0.142	0.182
16618000	7-day minimum	2.74	45	-0.020	-0.003	0.853	0.761	0.177	0.096
16618000	30-day minimum	2.84	45	0.040	0.010	0.703	0.884	0.178	0.094
16618000	1-day maximum	523	45	0.165	1.218	0.113	0.238	0.247	0.020
16618000	7-day maximum	471	45	0.164	0.582	0.115	0.187	0.183	0.086
16618000	30-day maximum	365	45	0.103	0.117	0.323	0.449	0.083	0.439
16620000	Q_{90} (total flow)	13	48	0.016	0.000	0.879	0.963	0.153	0.132
16620000	Q_{75} (total flow)	17	48	0.022	0.000	0.830	0.928	0.179	0.078
16620000	Q_{50} (total flow)	22	48	-0.007	0.000	0.950	0.857	0.194	0.056
16620000	Q_{25} (total flow)	38	48	-0.011	0.000	0.922	0.774	0.133	0.194
16620000	Q_{10} (total flow)	76	48	-0.071	-0.150	0.483	0.406	0.161	0.116
16620000	Mean (total flow)	37.4	48	-0.030	-0.021	0.769	0.654	0.215	0.036
16620000	Q_{90} (base flow)	12	48	0.002	0.000	0.993	0.913	0.136	0.182
16620000	Q_{75} (base flow)	14	48	0.005	0.000	0.964	0.973	0.171	0.093
16620000	Q_{50} (base flow)	17	48	0.017	0.002	0.873	0.937	0.145	0.158
16620000	Q_{25} (base flow)	21	48	-0.028	-0.012	0.783	0.726	0.145	0.158
16620000	Q_{10} (base flow)	26	48	-0.031	-0.016	0.762	0.677	0.210	0.041
16620000	Mean (base flow)	18.1	48	-0.039	-0.013	0.702	0.669	0.210	0.041
16620000	1-day minimum	8.50	48	-0.003	0.000	0.986	0.911	0.108	0.282
16620000	7-day minimum	8.50	48	0.036	0.009	0.722	0.867	0.143	0.163
16620000	30-day minimum	8.73	48	0.035	0.016	0.729	0.917	0.084	0.415
16620000	1-day maximum	779	48	0.021	0.400	0.838	0.986	0.024	0.820
16620000	7-day maximum	672	48	-0.046	-0.257	0.650	0.570	0.065	0.532
16620000	30-day maximum	537	48	-0.119	-0.240	0.237	0.209	0.117	0.256

[1]The Q_{pp} flow is the flow that is equaled or exceeded pp percent of the time.

[2]Attained significance level for the unmodified Mann-Kendall test.

[3]Attained significance level for the modified seasonal Mann-Kendall test.

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16019000	Q_{90} (total flow)	2.6	30	-0.011	0.000	0.943	0.985	0.005	0.985
16019000	Q_{75} (total flow)	3.6	30	-0.115	-0.018	0.381	0.373	-0.071	0.598
16019000	Q_{50} (total flow)	6.4	30	-0.193	-0.044	0.138	0.103	-0.170	0.201
16019000	Q_{25} (total flow)	15	30	-0.080	-0.057	0.543	0.571	-0.209	0.113
16019000	Q_{10} (total flow)	44	30	-0.198	-0.418	0.129	0.061	-0.172	0.195
16019000	Mean (total flow)	20.3	30	-0.090	-0.073	0.498	0.315	-0.207	0.119
16019000	Q_{90} (base flow)	2.3	30	0.152	0.009	0.246	0.275	0.005	0.985
16019000	Q_{75} (base flow)	2.7	30	0.025	0.001	0.858	0.798	0.086	0.523
16019000	Q_{50} (base flow)	3.4	30	-0.156	-0.017	0.232	0.211	-0.108	0.420
16019000	**Q_{25} (base flow)**	**4.9**	**30**	**-0.322**	**-0.069**	**0.013**	**0.018**	**-0.047**	**0.736**
16019000	**Q_{10} (base flow)**	**6.8**	**30**	**-0.333**	**-0.091**	**0.010**	**0.009**	**-0.113**	**0.399**
16019000	**Mean (base flow)**	**4.08**	**30**	**-0.260**	**-0.028**	**0.046**	**0.036**	**-0.084**	**0.536**
16019000	***1-day minimum***	***1.10***	***30***	***0.292***	***0.017***	***0.024***	***0.042***	***0.135***	***0.305***
16019000	7-day minimum	1.19	30	0.161	0.012	0.218	0.225	-0.084	0.535
16019000	30-day minimum	1.27	30	-0.087	-0.019	0.509	0.527	-0.064	0.639
16019000	1-day maximum	1010	30	0.055	1.857	0.682	0.790	0.059	0.666
16019000	7-day maximum	755	30	-0.002	-0.025	1.000	0.939	-0.049	0.722
16019000	30-day maximum	579	30	-0.122	-0.530	0.354	0.261	-0.089	0.511
16068000	Q_{90} (total flow)	15	30	0.092	0.063	0.485	0.495	0.103	0.438
16068000	Q_{75} (total flow)	20	30	0.085	0.000	0.516	0.584	0.059	0.660
16068000	Q_{50} (total flow)	29	30	-0.016	0.000	0.914	0.825	-0.086	0.520
16068000	Q_{25} (total flow)	46	30	-0.030	-0.045	0.830	0.651	-0.163	0.222
16068000	Q_{10} (total flow)	82	30	-0.032	-0.141	0.817	0.623	-0.064	0.639
16068000	Mean (total flow)	46.7	30	-0.025	-0.045	0.858	0.595	-0.074	0.586
16068000	Q_{90} (base flow)	14	30	0.152	0.077	0.245	0.293	0.135	0.309
16068000	Q_{75} (base flow)	17	30	0.156	0.089	0.232	0.274	0.143	0.285
16068000	Q_{50} (base flow)	23	30	-0.051	-0.027	0.708	0.729	0.039	0.778
16068000	Q_{25} (base flow)	29	30	-0.161	-0.153	0.218	0.210	-0.089	0.511
16068000	Q_{10} (base flow)	36	30	-0.232	-0.230	0.074	0.063	-0.039	0.778
16068000	Mean (base flow)	24.5	30	-0.090	-0.050	0.498	0.527	0.010	0.955
16068000	1-day minimum	8.00	30	0.117	0.056	0.368	0.396	0.155	0.236
16068000	7-day minimum	8.13	30	0.094	0.052	0.475	0.489	0.153	0.253
16068000	30-day minimum	8.47	30	0.124	0.107	0.344	0.372	0.059	0.666
16068000	1-day maximum	2570	30	0.044	2.857	0.748	1.000	-0.049	0.722
16068000	7-day maximum	1570	30	0.002	0.010	1.000	0.852	0.010	0.955
16068000	30-day maximum	1010	30	-0.094	-1.177	0.475	0.402	0.099	0.464

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16097500	Q_{90} (total flow)	4.6	30	0.055	0.008	0.681	0.897	0.217	0.101
16097500	Q_{75} (total flow)	5.7	30	0.018	0.004	0.901	0.922	0.207	0.119
16097500	Q_{50} (total flow)	7.3	30	-0.083	-0.020	0.532	0.463	0.293	0.027
16097500	Q_{25} (total flow)	11	30	-0.143	-0.045	0.274	0.240	0.118	0.372
16097500	Q_{10} (total flow)	20	30	-0.057	-0.043	0.668	0.597	0.143	0.283
16097500	Mean (total flow)	11.7	30	-0.016	-0.015	0.915	0.717	0.113	0.399
16097500	Q_{90} (base flow)	4.4	30	0.078	0.010	0.556	0.791	0.229	0.084
16097500	Q_{75} (base flow)	5.1	30	0.044	0.006	0.748	0.961	0.217	0.102
16097500	Q_{50} (base flow)	6.1	30	-0.048	-0.010	0.721	0.598	0.315	0.017
16097500	Q_{25} (base flow)	7.4	30	-0.168	-0.035	0.199	0.224	0.374	0.005
16097500	**Q_{10} (base flow)**	**8.9**	**30**	**-0.310**	**-0.069**	**0.017**	**0.034**	**0.310**	**0.019**
16097500	Mean (base flow)	6.44	30	-0.113	-0.017	0.392	0.347	0.276	0.037
16097500	1-day minimum	3.00	30	0.154	0.013	0.236	0.436	0.374	0.004
16097500	7-day minimum	3.00	30	0.126	0.014	0.335	0.540	0.283	0.032
16097500	30-day minimum	3.06	30	0.103	0.018	0.432	0.644	0.113	0.399
16097500	1-day maximum	879	30	0.168	3.091	0.199	0.267	0.049	0.721
16097500	7-day maximum	469	30	0.136	0.836	0.301	0.394	0.030	0.837
16097500	30-day maximum	270	30	0.007	0.008	0.972	0.986	0.084	0.536
16108000	Q_{90} (total flow)	49	30	0.071	0.063	0.591	0.710	0.217	0.101
16108000	Q_{75} (total flow)	58	30	0.071	0.068	0.592	0.699	0.153	0.251
16108000	Q_{50} (total flow)	79	30	0.069	0.192	0.605	0.623	0.039	0.778
16108000	Q_{25} (total flow)	134	30	0.000	0.000	1.000	0.918	-0.113	0.398
16108000	Q_{10} (total flow)	255	30	-0.002	-0.017	1.000	0.797	-0.138	0.302
16108000	Mean (total flow)	135	30	-0.021	-0.071	0.887	0.798	0.030	0.837
16108000	Q_{90} (base flow)	44	30	0.067	0.081	0.617	0.756	0.232	0.081
16108000	Q_{75} (base flow)	50	30	0.090	0.086	0.498	0.617	0.241	0.069
16108000	Q_{50} (base flow)	57	30	0.055	0.054	0.681	0.713	0.177	0.182
16108000	Q_{25} (base flow)	65	30	-0.007	-0.015	0.972	0.894	-0.015	0.925
16108000	Q_{10} (base flow)	75	30	0.016	0.036	0.915	0.803	-0.034	0.807
16108000	Mean (base flow)	58.7	30	0.053	0.044	0.695	0.696	0.163	0.223
16108000	1-day minimum	32.0	30	0.055	0.038	0.680	0.747	0.271	0.039
16108000	7-day minimum	32.9	30	0.071	0.068	0.592	0.699	0.288	0.029
16108000	30-day minimum	34.1	30	0.076	0.180	0.568	0.679	0.202	0.129
16108000	1-day maximum	3650	30	0.074	4.571	0.580	0.617	0.096	0.476
16108000	7-day maximum	2800	30	0.037	1.980	0.789	0.850	0.067	0.626
16108000	30-day maximum	2070	30	-0.145	-2.246	0.269	0.215	-0.039	0.778

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16200000	Q_{90} (total flow)	1.5	30	0.143	0.026	0.276	0.388	-0.044	0.749
16200000	Q_{75} (total flow)	3.2	30	0.195	0.038	0.134	0.234	0.074	0.586
16200000	Q_{50} (total flow)	6.4	30	0.078	0.032	0.556	0.643	-0.126	0.347
16200000	Q_{25} (total flow)	15	30	0.023	0.000	0.872	0.932	-0.153	0.250
16200000	Q_{10} (total flow)	35	30	0.044	0.053	0.748	0.958	-0.140	0.293
16200000	Mean (total flow)	15.1	30	0.062	0.038	0.643	0.869	-0.108	0.420
16200000	Q_{90} (base flow)	0.90	30	0.117	0.016	0.372	0.494	-0.054	0.694
16200000	Q_{75} (base flow)	1.9	30	0.216	0.033	0.097	0.165	0.096	0.476
16200000	Q_{50} (base flow)	3.3	30	0.200	0.038	0.125	0.165	-0.054	0.694
16200000	Q_{25} (base flow)	5.0	30	0.101	0.019	0.443	0.409	-0.160	0.230
16200000	Q_{10} (base flow)	7.2	30	0.002	0.001	1.000	0.933	-0.148	0.268
16200000	Mean (base flow)	3.78	30	0.117	0.019	0.372	0.404	-0.123	0.358
16200000	1-day minimum	0.13	30	0.163	0.012	0.211	0.260	-0.108	0.418
16200000	7-day minimum	0.13	30	0.108	0.009	0.412	0.498	-0.084	0.536
16200000	30-day minimum	0.15	30	0.103	0.035	0.432	0.455	-0.202	0.129
16200000	1-day maximum	743	30	-0.030	-0.353	0.830	0.531	-0.017	0.910
16200000	7-day maximum	571	30	0.016	0.098	0.915	0.751	-0.059	0.666
16200000	30-day maximum	358	30	-0.057	-0.079	0.669	0.354	-0.118	0.378
16211600	Q_{90} (total flow)	0.00	30	-0.294	-0.003	0.019	0.081	0.411	0.001
16211600	Q_{75} (total flow)	0.11	30	-0.283	-0.008	0.029	0.100	0.382	0.004
16211600	Q_{50} (total flow)	0.49	30	-0.205	-0.015	0.115	0.227	0.355	0.007
16211600	Q_{25} (total flow)	1.2	30	-0.257	-0.038	0.048	0.092	0.271	0.041
16211600	**Q_{10} (total flow)**	**2.9**	**30**	**-0.303**	**-0.084**	**0.019**	**0.039**	**0.256**	**0.053**
16211600	Mean (total flow)	1.55	30	-0.274	-0.035	0.035	0.051	0.148	0.268
16211600	Q_{90} (base flow)	0.00	30	-0.280	-0.002	0.024	0.087	0.374	0.002
16211600	**Q_{75} (base flow)**	**0.04**	**30**	**-0.361**	**-0.006**	**0.005**	**0.038**	**0.478**	**0.000**
16211600	Q_{50} (base flow)	0.27	30	-0.234	-0.009	0.070	0.175	0.389	0.003
16211600	Q_{25} (base flow)	0.64	30	-0.274	-0.019	0.035	0.077	0.347	0.009
16211600	Q_{10} (base flow)	1.2	30	-0.287	-0.031	0.027	0.064	0.318	0.016
16211600	Mean (base flow)	0.47	30	-0.260	-0.014	0.046	0.109	0.374	0.005
16211600	1-day minimum	0.00	30	-0.214	0.000	0.078	0.179	0.333	0.004
16211600	7-day minimum	0.00	30	-0.223	0.000	0.066	0.165	0.333	0.004
16211600	30-day minimum	0.00	30	-0.306	-0.002	0.017	0.078	0.401	0.002
16211600	1-day maximum	283	30	-0.048	-0.307	0.721	0.518	-0.010	0.955
16211600	7-day maximum	162	30	-0.071	-0.159	0.592	0.450	0.000	1.000
16211600	30-day maximum	93.4	30	-0.191	-0.107	0.143	0.103	0.074	0.586

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16226000	Q_{90} (total flow)	0.00	30	0.014	0.000	0.915	0.902	-0.094	0.330
16226000	Q_{75} (total flow)	0.02	30	0.064	0.000	0.617	0.621	0.069	0.590
16226000	Q_{50} (total flow)	0.34	30	0.071	0.003	0.592	0.732	0.022	0.881
16226000	Q_{25} (total flow)	2.3	30	0.000	0.000	1.000	0.907	-0.044	0.750
16226000	Q_{10} (total flow)	9.5	30	-0.009	-0.004	0.957	0.840	0.039	0.778
16226000	Mean (total flow)	4.23	30	0.011	0.001	0.943	0.853	0.010	0.955
16226000	Q_{90} (base flow)	0.00	30	0.021	0.000	0.864	0.846	-0.076	0.427
16226000	Q_{75} (base flow)	0.00	30	0.034	0.000	0.785	0.787	0.057	0.627
16226000	Q_{50} (base flow)	0.03	30	-0.113	0.000	0.387	0.372	0.027	0.848
16226000	Q_{25} (base flow)	0.17	30	0.000	0.000	1.000	0.837	-0.128	0.337
16226000	Q_{10} (base flow)	0.62	30	-0.115	-0.006	0.382	0.237	-0.101	0.453
16226000	Mean (base flow)	0.21	30	-0.078	-0.001	0.556	0.387	-0.047	0.736
16226000	1-day minimum	0.00	30	0.053	0.000	0.448	0.403	-0.022	0.588
16226000	7-day minimum	0.00	30	0.092	0.000	0.281	0.314	0.069	0.239
16226000	30-day minimum	0.00	30	0.223	0.000	0.076	0.125	0.039	0.763
16226000	1-day maximum	360	30	-0.152	-2.000	0.246	0.109	0.062	0.652
16226000	7-day maximum	290	30	-0.108	-0.396	0.412	0.244	0.044	0.750
16226000	30-day maximum	187	30	-0.140	-0.141	0.284	0.165	0.054	0.694
16229000	Q_{90} (total flow)	0.82	30	0.216	0.015	0.097	0.219	0.244	0.065
16229000	Q_{75} (total flow)	1.3	30	0.154	0.014	0.238	0.388	0.143	0.282
16229000	Q_{50} (total flow)	2.3	30	0.057	0.004	0.667	0.773	-0.002	1.000
16229000	Q_{25} (total flow)	4.5	30	-0.041	-0.011	0.761	0.632	0.017	0.910
16229000	Q_{10} (total flow)	9.1	30	-0.002	0.000	1.000	0.781	0.025	0.866
16229000	Mean (total flow)	5.19	30	0.002	0.001	1.000	0.772	0.069	0.613
16229000	Q_{90} (base flow)	0.60	30	0.262	0.017	0.044	0.132	0.288	0.029
16229000	Q_{75} (base flow)	0.96	30	0.159	0.010	0.225	0.386	0.202	0.128
16229000	Q_{50} (base flow)	1.6	30	0.074	0.007	0.580	0.770	0.076	0.574
16229000	Q_{25} (base flow)	2.3	30	0.016	0.002	0.915	1.000	0.005	0.985
16229000	Q_{10} (base flow)	3.4	30	-0.078	-0.021	0.556	0.458	-0.010	0.955
16229000	Mean (base flow)	1.84	30	0.016	0.002	0.915	0.957	0.074	0.586
16229000	***1-day minimum***	***0.15***	***30***	***0.372***	***0.015***	***0.004***	***0.034***	***0.419***	***0.001***
16229000	***7-day minimum***	***0.16***	***30***	***0.375***	***0.019***	***0.004***	***0.029***	***0.384***	***0.004***
16229000	30-day minimum	0.19	30	0.209	0.019	0.108	0.237	0.286	0.031
16229000	1-day maximum	327	30	-0.115	-0.955	0.382	0.248	0.118	0.378
16229000	7-day maximum	247	30	-0.071	-0.296	0.592	0.388	0.113	0.399
16229000	30-day maximum	171	30	-0.071	-0.123	0.592	0.384	0.133	0.320

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

				Relation between flow and time				Relation between flow and previous year's flow	
Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16303003	Q_{90} (total flow)	13	30	0.211	0.096	0.104	0.236	0.426	0.001
16303003	Q_{75} (total flow)	15	30	0.175	0.093	0.180	0.346	0.310	0.019
16303003	Q_{50} (total flow)	18	30	0.097	0.074	0.464	0.667	0.212	0.111
16303003	Q_{25} (total flow)	23	30	-0.002	-0.002	1.000	0.793	0.113	0.399
16303003	Q_{10} (total flow)	33	30	0.011	0.033	0.943	0.817	0.103	0.442
16303003	Mean (total flow)	23.6	30	0.085	0.062	0.521	0.802	0.172	0.196
16303003	Q_{90} (base flow)	12	30	0.237	0.091	0.069	0.179	0.433	0.001
16303003	Q_{75} (base flow)	14	30	0.193	0.085	0.139	0.282	0.355	0.007
16303003	Q_{50} (base flow)	17	30	0.136	0.068	0.301	0.494	0.236	0.075
16303003	Q_{25} (base flow)	20	30	0.016	0.008	0.915	0.966	0.180	0.177
16303003	Q_{10} (base flow)	23	30	0.044	0.025	0.748	0.987	0.251	0.058
16303003	Mean (base flow)	17.2	30	0.140	0.062	0.284	0.476	0.291	0.028
16303003	1-day minimum	8.40	30	0.290	0.107	0.026	0.067	0.271	0.041
16303003	7-day minimum	8.64	30	0.297	0.124	0.022	0.083	0.488	0.000
16303003	30-day minimum	9.05	30	0.209	0.104	0.108	0.217	0.335	0.011
16303003	1-day maximum	740	30	-0.021	-0.560	0.887	0.494	0.025	0.866
16303003	7-day maximum	511	30	-0.023	-0.175	0.872	0.514	0.079	0.561
16303003	30-day maximum	334	30	-0.113	-0.242	0.392	0.241	0.217	0.103
16400000	Q_{90} (total flow)	4.3	30	0.131	0.029	0.318	0.446	0.039	0.778
16400000	Q_{75} (total flow)	6.5	30	0.124	0.040	0.344	0.461	0.022	0.881
16400000	Q_{50} (total flow)	12	30	0.129	0.057	0.323	0.387	-0.037	0.790
16400000	Q_{25} (total flow)	29	30	0.179	0.240	0.169	0.247	0.089	0.510
16400000	Q_{10} (total flow)	66	30	0.103	0.290	0.432	0.580	0.084	0.536
16400000	Mean (total flow)	28.5	30	0.108	0.131	0.412	0.604	0.138	0.302
16400000	Q_{90} (base flow)	3.1	30	0.147	0.024	0.261	0.423	0.020	0.895
16400000	Q_{75} (base flow)	4.1	30	0.143	0.035	0.276	0.394	0.015	0.925
16400000	Q_{50} (base flow)	5.7	30	0.163	0.034	0.212	0.303	0.020	0.896
16400000	Q_{25} (base flow)	7.6	30	0.087	0.021	0.509	0.675	-0.015	0.925
16400000	Q_{10} (base flow)	9.6	30	0.007	0.000	0.971	0.893	0.067	0.625
16400000	Mean (base flow)	6.09	30	0.131	0.028	0.318	0.471	0.103	0.442
16400000	1-day minimum	1.10	30	0.205	0.033	0.116	0.185	0.143	0.283
16400000	7-day minimum	1.21	30	0.147	0.031	0.261	0.335	0.150	0.260
16400000	30-day minimum	1.43	30	0.207	0.093	0.112	0.203	0.064	0.639
16400000	1-day maximum	757	30	-0.048	-0.955	0.721	0.496	0.300	0.023
16400000	7-day maximum	704	30	0.076	0.646	0.568	0.852	0.305	0.021
16400000	30-day maximum	520	30	0.025	0.111	0.858	0.909	0.222	0.095

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time				Relation between flow and previous year's flow	
				Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16508000	Q_{90} (total flow)	2.5	30	0.193	0.019	0.138	0.232	0.002	1.000
16508000	Q_{75} (total flow)	3.6	30	0.216	0.036	0.097	0.178	0.099	0.464
16508000	Q_{50} (total flow)	6.5	30	0.205	0.075	0.116	0.181	0.034	0.807
16508000	Q_{25} (total flow)	15	30	0.140	0.158	0.283	0.278	-0.059	0.665
16508000	Q_{10} (total flow)	54	30	0.085	0.308	0.521	0.561	-0.054	0.693
16508000	Mean (total flow)	25.3	30	0.067	0.108	0.617	0.729	-0.059	0.666
16508000	Q_{90} (base flow)	2.3	30	0.211	0.014	0.104	0.172	-0.094	0.487
16508000	Q_{75} (base flow)	2.9	30	0.143	0.012	0.276	0.373	0.000	1.000
16508000	Q_{50} (base flow)	4.1	30	0.248	0.038	0.056	0.104	0.096	0.476
16508000	Q_{25} (base flow)	6.2	30	0.122	0.046	0.354	0.382	-0.099	0.464
16508000	Q_{10} (base flow)	8.7	30	-0.002	0.000	1.000	0.819	-0.246	0.063
16508000	Mean (base flow)	5.11	30	0.129	0.024	0.326	0.352	-0.069	0.612
16508000	1-day minimum	0.90	30	0.237	0.020	0.068	0.090	-0.094	0.484
16508000	7-day minimum	0.95	30	0.248	0.021	0.056	0.075	-0.074	0.586
16508000	30-day minimum	1.09	30	0.207	0.029	0.112	0.163	-0.054	0.694
16508000	1-day maximum	1170	30	-0.117	-5.467	0.372	0.275	-0.034	0.807
16508000	7-day maximum	1040	30	-0.025	-0.312	0.858	0.811	-0.069	0.613
16508000	30-day maximum	803	30	-0.025	-0.165	0.858	0.920	-0.084	0.536
16587000	Q_{90} (total flow)	0.60	30	0.124	0.006	0.344	0.609	0.158	0.236
16587000	Q_{75} (total flow)	1.1	30	0.067	0.006	0.617	0.789	0.067	0.625
16587000	Q_{50} (total flow)	2.2	30	0.090	0.011	0.497	0.595	-0.052	0.706
16587000	Q_{25} (total flow)	4.7	30	0.168	0.030	0.199	0.261	0.084	0.535
16587000	Q_{10} (total flow)	9.6	30	0.145	0.080	0.268	0.280	0.059	0.666
16587000	Mean (total flow)	4.84	30	0.140	0.036	0.284	0.326	0.103	0.442
16587000	Q_{90} (base flow)	0.47	30	0.106	0.005	0.422	0.658	0.108	0.420
16587000	Q_{75} (base flow)	0.79	30	0.060	0.003	0.655	0.748	0.059	0.666
16587000	Q_{50} (base flow)	1.4	30	0.046	0.003	0.735	0.881	0.000	1.000
16587000	Q_{25} (base flow)	2.2	30	0.062	0.006	0.643	0.846	-0.039	0.778
16587000	Q_{10} (base flow)	3.3	30	0.000	0.000	1.000	0.784	-0.236	0.074
16587000	Mean (base flow)	1.71	30	0.078	0.005	0.556	0.620	-0.025	0.866
16587000	1-day minimum	0.11	30	0.124	0.004	0.343	0.562	0.047	0.734
16587000	7-day minimum	0.11	30	0.147	0.005	0.261	0.480	0.138	0.302
16587000	30-day minimum	0.13	30	0.152	0.009	0.246	0.437	0.049	0.721
16587000	1-day maximum	305	30	0.110	1.000	0.402	0.469	0.049	0.721
16587000	7-day maximum	254	30	0.053	0.235	0.695	0.707	0.000	1.000
16587000	30-day maximum	148	30	0.099	0.132	0.454	0.425	0.025	0.866

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

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bold italic blue type indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test;
cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time				Relation between flow and previous year's flow	
				Tau coefficient	Slope, in cfs/yr	2p-value (ignoring serial correlation)[2]	2p-value (accounting for serial correlation)[3]	Tau coefficient	2p-value
16618000	Q_{90} (total flow)	4.9	27	-0.017	-0.004	0.917	0.887	0.212	0.133
16618000	Q_{75} (total flow)	6.1	27	-0.020	-0.001	0.900	0.896	0.086	0.551
16618000	Q_{50} (total flow)	8.8	27	-0.034	-0.004	0.818	0.816	0.080	0.580
16618000	Q_{25} (total flow)	16	27	-0.037	0.000	0.801	0.795	0.068	0.640
16618000	Q_{10} (total flow)	37	27	0.023	0.034	0.884	0.937	0.151	0.290
16618000	Mean (total flow)	18.5	27	-0.037	-0.023	0.802	0.770	0.077	0.597
16618000	Q_{90} (base flow)	4.4	27	-0.011	-0.001	0.950	0.910	0.218	0.123
16618000	Q_{75} (base flow)	5.0	27	0.014	0.004	0.934	0.984	0.145	0.311
16618000	Q_{50} (base flow)	6.1	27	-0.074	-0.019	0.602	0.621	0.065	0.659
16618000	Q_{25} (base flow)	7.8	27	-0.120	-0.034	0.393	0.435	0.163	0.251
16618000	Q_{10} (base flow)	9.5	27	-0.165	-0.100	0.235	0.297	0.206	0.146
16618000	Mean (base flow)	6.61	27	-0.117	-0.036	0.404	0.434	0.169	0.234
16618000	1-day minimum	2.70	27	-0.040	-0.004	0.786	0.754	0.182	0.199
16618000	7-day minimum	2.74	27	-0.071	-0.012	0.617	0.607	0.175	0.217
16618000	30-day minimum	2.84	27	0.094	0.037	0.505	0.585	0.151	0.290
16618000	1-day maximum	523	27	-0.271	-7.000	0.050	0.073	0.268	0.058
16618000	7-day maximum	471	27	-0.208	-2.541	0.133	0.170	0.114	0.427
16618000	30-day maximum	356	27	-0.134	-0.500	0.338	0.319	0.065	0.659
16620000	Q_{90} (total flow)	13	28	0.270	0.100	0.043	0.109	0.178	0.197
16620000	Q_{75} (total flow)	16	28	0.262	0.103	0.050	0.135	0.197	0.154
16620000	Q_{50} (total flow)	22	28	0.193	0.140	0.153	0.266	0.163	0.247
16620000	Q_{25} (total flow)	38	28	0.183	0.304	0.179	0.270	0.095	0.507
16620000	Q_{10} (total flow)	73	28	0.217	0.620	0.110	0.205	0.108	0.454
16620000	Mean (total flow)	37.0	28	0.196	0.192	0.149	0.257	0.175	0.217
16620000	Q_{90} (base flow)	12	28	0.222	0.085	0.099	0.216	0.117	0.408
16620000	Q_{75} (base flow)	14	28	0.275	0.089	0.041	0.109	0.197	0.160
16620000	Q_{50} (base flow)	16	28	0.190	0.077	0.160	0.273	0.160	0.260
16620000	Q_{25} (base flow)	21	28	0.124	0.088	0.363	0.495	0.163	0.251
16620000	Q_{10} (base flow)	26	28	0.095	0.104	0.489	0.685	0.286	0.043
16620000	Mean (base flow)	18.0	28	0.159	0.094	0.244	0.391	0.194	0.172
16620000	1-day minimum	8.50	28	0.190	0.075	0.155	0.272	0.129	0.352
16620000	7-day minimum	8.50	28	0.249	0.101	0.066	0.139	0.142	0.320
16620000	30-day minimum	8.82	28	0.243	0.193	0.072	0.149	0.083	0.567
16620000	1-day maximum	779	28	-0.130	-2.464	0.343	0.349	0.132	0.354
16620000	7-day maximum	663	28	0.053	0.451	0.707	0.918	0.028	0.860
16620000	30-day maximum	504	28	0.085	0.290	0.540	0.662	-0.003	1.000

Table 5. Results of Mann-Kendall test for trends in annual flows during 1973 to 2002 at long-term-trend stations, Hawaii.—Continued

[**bold red type** indicates statistically significant negative-trend (5-percent level) using the modified seasonal Mann-Kendall test; ***bold italic blue type*** indicates statistically significant positive-trend (5-percent level) using the modified seasonal Mann-Kendall test; cfs, cubic feet per second; cfs/yr, cubic feet per second per year; 2p-value, significance level attained by the data]

Station	Flow parameter[1]	Flow value over period, in cfs	No. water years	Relation between flow and time: Tau coefficient	Relation between flow and time: Slope, in cfs/yr	Relation between flow and time: 2p-value (ignoring serial correlation)[2]	Relation between flow and time: 2p-value (accounting for serial correlation)[3]	Relation between flow and previous year's flow: Tau coefficient	Relation between flow and previous year's flow: 2p-value
16717000	Q_{90} (total flow)	11	30	0.110	0.113	0.401	0.485	0.167	0.208
16717000	Q_{75} (total flow)	20	30	0.163	0.179	0.210	0.323	0.086	0.521
16717000	Q_{50} (total flow)	42	30	0.202	0.458	0.120	0.219	0.069	0.612
16717000	***Q_{25} (total flow)***	***97***	***30***	***0.285***	***1.400***	***0.028***	***0.048***	***-0.015***	***0.925***
16717000	Q_{10} (total flow)	266	30	0.136	1.951	0.301	0.346	-0.158	0.237
16717000	Mean (total flow)	130	30	0.085	0.570	0.521	0.674	-0.128	0.339
16717000	Q_{90} (base flow)	8.3	30	0.228	0.148	0.080	0.156	0.256	0.053
16717000	Q_{75} (base flow)	13	30	0.246	0.168	0.059	0.139	0.153	0.253
16717000	Q_{50} (base flow)	22	30	0.154	0.173	0.239	0.357	0.103	0.442
16717000	Q_{25} (base flow)	36	30	0.145	0.185	0.269	0.314	-0.025	0.866
16717000	Q_{10} (base flow)	53	30	0.177	0.403	0.175	0.184	0.025	0.866
16717000	Mean (base flow)	27.7	30	0.200	0.217	0.125	0.157	0.030	0.837
16717000	1-day minimum	1.00	30	0.267	0.137	0.040	0.104	0.239	0.071
16717000	7-day minimum	1.01	30	0.175	0.108	0.181	0.291	0.207	0.119
16717000	30-day minimum	1.53	30	0.034	0.032	0.803	0.880	0.153	0.253
16717000	1-day maximum	6410	30	0.005	0.909	0.986	1.000	0.005	0.985
16717000	7-day maximum	5510	30	-0.007	-0.210	0.972	0.805	-0.005	0.985
16717000	30-day maximum	4210	30	-0.007	-0.106	0.972	0.918	-0.113	0.399
16720000	Q_{90} (total flow)	0.51	30	-0.021	-0.001	0.887	0.898	0.005	0.985
16720000	Q_{75} (total flow)	1.4	30	-0.053	-0.006	0.694	0.678	0.044	0.749
16720000	Q_{50} (total flow)	4.8	30	0.106	0.030	0.421	0.516	0.064	0.637
16720000	Q_{25} (total flow)	18	30	0.115	0.075	0.380	0.458	-0.084	0.533
16720000	Q_{10} (total flow)	42	30	0.106	0.231	0.422	0.466	-0.074	0.586
16720000	Mean (total flow)	15.6	30	0.048	0.053	0.721	0.812	-0.089	0.511
16720000	Q_{90} (base flow)	0.25	30	0.117	0.005	0.372	0.414	0.148	0.268
16720000	Q_{75} (base flow)	0.53	30	0.078	0.004	0.556	0.573	0.207	0.119
16720000	Q_{50} (base flow)	1.2	30	0.051	0.005	0.708	0.841	0.172	0.195
16720000	Q_{25} (base flow)	2.3	30	0.149	0.019	0.254	0.296	0.103	0.442
16720000	***Q_{10} (base flow)***	***4.1***	***30***	***0.290***	***0.072***	***0.026***	***0.034***	***0.020***	***0.895***
16720000	Mean (base flow)	1.82	30	0.209	0.022	0.108	0.170	0.128	0.339
16720000	1-day minimum	0.01	30	0.280	0.005	0.030	0.053	0.175	0.186
16720000	7-day minimum	0.01	30	0.175	0.004	0.181	0.176	0.096	0.476
16720000	30-day minimum	0.02	30	-0.168	-0.034	0.199	0.226	0.049	0.722
16720000	1-day maximum	612	30	0.080	0.850	0.544	0.746	-0.094	0.487
16720000	7-day maximum	466	30	0.126	0.708	0.335	0.403	-0.059	0.666
16720000	30-day maximum	309	30	0.039	0.091	0.775	0.658	-0.025	0.866

[1]The Q_{pp} flow is the flow that is equaled or exceeded pp percent of the time.

[2]Attained significance level for the unmodified Mann-Kendall test.

[3]Attained significance level for the modified seasonal Mann-Kendall test.